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AN APPARENT HIGH PRESSURE DUE TO ADSORPTION, THE HEAT OF ADSORPTION, AND THE DENSITY OF GAS-MASK CHARCOALS

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A knowledge of the volume of the pores, and of the density of the active carbon in gas-mask charcoal, is of importance in connection with the working out of a theory in regard to the efficiency of charcoal as an adsorbent of gases, so the problem of the determination of the pore volume was given to us by the National Research Council in connection with the work of problem 108. We have discovered that factors which have hitherto been unsuspected complicate such a determination, the interesting new phenomenon being that the volume of the liquid absorbed depends upon the physical properties of the liquid. Thus it has been found that the volume of water or of an organic liquid taken up by a definite weight of any charcoal which is very efficient as an adsorber of gases, increases as the compressibility of the liquid increases, or as either the viscosity or the surface tension decreases. This effect decreases as the adsorptive capacity decreases, and entirely disappears when the charcoal becomes valueless as a gas adsorbent.

While effects of the same general order were found whether the charcoal was put in the liquid directly from the canisters or from the bottles in which it was stored, or only after an extensive "outgassing" or heating and pumping out of the gases contained in it, concordant results were obtained only by the latter procedure. This is a well-known method for cleaning the surface of the charcoal, and the only new features introduced were those which concerned the completeness of the outgassing. The tube containing the charcoal was first exhausted by a rapid mercury condensation pump, and then heated up very slowly in vacuo until the temperature finally reached 600° C., keeping the pump running. The heating and evacuating usually continued for two days, though this time varied greatly with the nature of the charcoal, and was only ended when the pressure in the system fell to one ten-thousandth of a millimeter at this high temperature,

and remained of that order for about six hours. The tube was sealed off while still at 600°, and was then opened under the hot liquid which had just been boiled to drive off dissolved gases. In some cases the charcoal was treated with the vapor of the liquid while it was still in the vacuum apparatus, and was then subjected to a second outgassing. It was found that it was not sufficient to reduce the pressure to 0.0001 mm. but that this low pressure had to be maintained for hours, if concordant results were to be obtained. Those who are familiar with vacuum work will realize that when a bulb almost completely filled with active charcoal is kept at 0.0001 mm. for hours at 600° C., a very low pressure when the temperature is considered, and is sealed off at this temperature and pressure, the pressure on cooling will fall to an exceedingly low value. It is probable that this pressure is much lower than can be obtained with the extremely efficient condensation pumps, that is, the pressure is probably lower than has ever been measured.

A few of the results obtained by us for a high-grade, steam-activated charcoal (E 602), a 47.2 minute charcoal as determined by the accelerated chlorpicrin test, or about 700 minutes by the ordinary test, are given in table 1. The densities given here are those which the carbon would have if it filled all the space not occupied by the liquid, and if the liquids were incompressible. The densities given are the averages of very closely agreeing values.

TABLE 1

DENSITY AND PORE-VOLUME DETERMINATIONS FOR A STEAM-ACTIVATED COCOANUT SHELL GAS-MASK CHARCOAL (DATA AT 20° C.)

1 LIQUID	2 DENSITY	3 PORE VOLUME IN 1 CU. CM.	4 PER CENT COMPRESSED 12000 ATMOSPHERES[1]	5 SURFACE TENSION DYNES PER CM.	6 VISCOSITY IN ABSOLUTE UNITS
Mercury	0.865			57.0	
Water	1.843	0.534	20.51	72.8	0.0101
Propyl alcohol	1.960	0.559	22.93	23.7	0.0223
Chloroform	1.992	0.566		27.13	0.0057
Benzene	2.008	0.568		28.88	0.0064
para-Xylene	2.018	0.571		28.33	0.0064
Petroleum ether	2.042	0.579			
Carbon bisulphide	2.057	0.580	25.37	31.38	0.0037
Acetone	2.112	0.590	27.0	23.50	0.0033
Ether	2.120	0.592	30.0	17.1	0.0024
Pentane	2.129	0.593	More than ether	About 15	0.0024

[1] NOTE.—The solubility of gases in these liquids increases in *general* with the percent of compression or the compressibility, but the order is not exactly the same. The values for the density and for the pore volume listed in this table are calculated on the basis of the incorrect assumption that the liquids are incompressible. The same values would be obtained if the liquids are compressible but are not compressed.

When a tube containing the charcoal is outgassed, and mercury is admitted, this liquid fills what are technically known as the *voids* between the lumps, but we have found that it does not enter the very small *pores* in the lumps, so in this way the total volume of the lumps, and also the lump or "block" density, may be determined. For the charcoal given in table 1 this is 0.865. What is known as the apparent density of a charcoal is the mass of the charcoal contained in a 100 cu. cm. flask divided by 100, or it is the density of the carbon, pores, and voids, all taken together, and is usually about 0.5 for charcoals used by the Chemical Warfare Service. What is known usually as the "real density," though it is not the actual density, is that which is obtained by allowing water to penetrate the pores and by calculating the "real volume" of the carbon on the basis of the assumptions that the water completely fills the pores and that the water is not compressed by the attraction of the charcoal. The data of column 2 show that both of these assumptions cannot be correct. The densities of cocoanut shell charcoals as used by us when determined in water are 1.843 (table 1), 1.863, 1.835, and 1.808; that of the similar charcoal used, by Titoff,[1] 1.86; by Baerwald,[2] 1.92; and by Miss Homfray,[3] 1.66.

The compressibility data in table 1 are those of Bridgman,[4] those on surface tension were obtained in this laboratory, and the viscosity data, by different investigators. The compressibility increases in exactly the same order as either the pore volume or the density, except that the individual order for chloroform, benzene, and paraxylene is not known, though a study of Bridgman's curves of compression taken in connection with Richard's[5] data on their compressibility up to 500 atmospheres, makes the conclusion inevitable that as a class they lie between propyl alcohol and carbon bisulphide in accordance with their position in table 1. The curves plotted from Bridgman's data do not in general cross each other when all of the liquids are non-polar, while the curves for polar liquids not only cross each other, but also those for non-polar liquids.

The data indicate that the differences in the volume of liquid absorbed in 1 cu. cm. of the charcoal, listed as the pore volume in table 1, may be due either to the compressibility or the viscosity of the liquid, but on the whole they are in better agreement with the idea that it is the compressibility which is effective. The difference between the volume of ether and water absorbed is about 10%, and to produce this difference of volume by pressure exerted on the whole volume of liquid would require, according to Bridgman's data, between four and twelve thousand atmospheres. It is evident, however, that only a small fraction of the liquid is in actual contact with the charcoal. Dr. A. M. Williams[6] has calculated the volume of liquid in the primary film in the cocoanut charcoal used by Titoff as 0.30 ccm., which would be of the order of three-fifths of the pore volume. This would show that the average pressure in the primary film due to the

attraction of the carbon is extremely high, and while the difference between the compression of ether and that of water does not vary in such a way as to make it possible to give an exact estimate, the pressure would probably need to be more than *twenty thousand atmospheres* higher than the normal internal pressure of the liquid. The film, according to Williams, has an average thickness of 4×10^{-8} cm., which is of the order of one or two molecules in thickness for molecules of the dimensions used in our work. The magnitude of this pressure, which is the amount that the adhesional pressure betwen the carbon and the liquid *exceeds* that in the liquid itself, is not at all surprising. The deductions from the compressibility theory indicate, if the theory is on a sound basis, that the average pressure given in our experiments is of the order of twice to three times as great as the highest pressures obtained by Bridgman.

This theory leads to low values for the density of active carbon, or a density of about 1.6. Some of the charcoals which we have studied do not absorb more ether than they do water, or this compressive effect seems wanting. These are just the charcoals which are extremely inefficient in adsorbing gases, that is, cedar wood charcoal, with a density of 1.50, and beechwood charcoal with a density of 1.65, which values are of the same order of magnitude as that calculated for cocoanut shell charcoal, or as the density in water of the rather low-grade cocoanut shell charcoal used by Miss Homfray. A charcoal made from anthracite coal alone has a density of 1.876 in water, and only 1.906 in ether, while a sample of carbonite (made from anthracite and pitch) of 19 minutes accelerated chlorpicrin test had a density of 1.934 in water and 2.075 in ether.

The data of table 1 suggest still another theory, that the differences in the volumes of the liquids absorbed are due to their viscosity, the idea being that some of the pores are so fine that the liquids which are more viscous are less able to penetrate than those which are more fluid, at least in the time allowed for penetration, from 24 to 48 hours. The first results which we obtained indicated that the quantity of liquid absorbed increases with the time, but this time effect disappeared when we adopted the extremely thorough method of outgassing previously described. We have heard that Professor Hulett of Princeton University has found such a time effect, but presumably on less highly outgassed charcoals. Mr. Monroe is now engaged in a study of this effect under the conditions used in our tests. The principal evidence against the viscosity theory to be found in the data of table 1, is that the viscosity value obtained for propyl alcohol is badly out of order, since propyl alcohol is twice as viscous as water, yet much more of the propyl alcohol penetrates the pores. This accords exactly with the compressibility theory.

Experiments on the heat of adsorption of liquids gave some interesting results. A highly outgassed cocoanut shell charcoal gave a heat of adsorption equal to 10.5 calories per gram of charcoal when immersed in water

enough to completely fill its pores and voids. The same charcoal dried for ten days at 120 to 150° C., and then cooled over phosphorus pentoxide, had a smaller heat of adsorption, 7.0 calories, while it gave only 3.5 calories when it held a thin film of water equal to 0.04 gram per gram of charcoal. Thus the first tenth of the water which penetrates the pores gives rise to nearly all of the evolution of heat. Such experiments as this are now being carried out by precise methods, carefully measuring each amount of water added, in somewhat the same way as Titoff carried out his experiments on the heat of adsorption of gases, but with a number of added precautions. The results indicate that, in accord with the theory of Langmuir[7] and in agreement with the work of this laboratory on surfaces, the forces of adsorption or adhesion act only on an extremely thin layer of liquid.

The heat of adsorption of bone charcoal which had not been outgassed was found to be 18.5 calories, and in fullers' earth it was 32 calories, or almost the same values as were obtained by Gurvich[8] (18.5 and 30.2). Thus both of these solids have a very much higher heat of adsorption than even the best grades of cocoanut shell charcoal. While commonly known as the heat of adsorption, this is more precisely designated as the heat of spreading of a liquid on the surface of a solid. If $-Q$ is taken to represent the heat given off per square centimeter of surface; γ, the free surface energy; l, the latent heat of the surface; $-\Delta E$, the decrease of surface energy in spreading, and the subscript sp represents spreading; s, the solid, a and i, the interface, then

$$-Q_{sp} = -\Delta E_{sp} = \gamma_s + l_s - (\gamma_i + l_i). \quad (1)$$

The adhesional heat and energy are defined by the equation

$$-Q_A = E_A = -\Delta E_s = \gamma_s + l_s + \gamma_l + l_l - (\gamma_i + l_i) \quad (2)$$

or

$$-Q_{sp} = -Q_A - (\gamma_l + l_l). \quad (3)$$

The heat of adsorption of enough gas to form a liquid in bulk, covering the solid surface at constant temperature (Q_T), is given by the equation

$$-Q_T = \gamma_s + l_s - (\gamma_i + l_i) + \lambda v \quad (4)$$

where λ is the latent heat of vaporization of the liquid per unit volume of vapor. While we do not have the values of these quantities in the case of carbon, they have been determined in this laboratory for the interfaces between either mercury or water, and other liquids. The Pouillet effect, which is the heat given out when a liquid is adsorbed by a powder and is entirely analogous to that described here, has been attributed to the *compression* of the surface film of the liquid in contact with the powder. This compression, which was merely assumed from the standpoint of ideas on molecular attraction, is practically the same as that for which moderately direct evidence has been given in this paper. However, the above equations, which were developed by Harkins, show that the heat comes from

the total energy changes in the film, which include both the solid carbon and the liquid of the interface. This heat is entirely analogous to that developed when a body falls from a height above the earth to its surface, when the mutual potential energy of the body and the earth are converted into molecular kinetic energy, or heat. In a similar way, when the surface of the liquid and of the carbon fall together, their mutual potential energy of molecular attraction, due to electromagnetic (largely electrical) forces, is converted into molecular kinetic energy, which is heat.

This theory of the heat of adsorption has been developed by Harkins, but has not been published, although the fundamental equations upon which it is based have been published in these PROCEEDINGS. The final equations, (1) and (4), as given above, were not, however, presented. The experimental work on interfaces as carried out in this laboratory indicates that the γ_s of equation (1) is very large, and that most of the heat which appears is due to the fact that the interfacial free energy carbon-liquid is very much smaller than the free surface energy of the solid carbon. Equation (3) shows that the heat of adsorption of the liquid is equal to the energy of adhesion between the liquid and the carbon, minus the total surface energy of the liquid. In the case of water this total surface energy is moderately large, so the heat of spreading of the liquid is considerably less than the adhesional energy.

If further data agree with those already found in indicating that the differences in the volumes of various liquids absorbed by activated cocoanut shell and other highly activated charcoals are due to a compression by the forces of adhesion of the order of twenty thousand atmospheres as the average pressure in a film of 4×10^{-8} cm. in thickness, which would indicate a much higher pressure for the first layer of atoms, then the results presented in this paper will be the first direct evidence of the existence of such high forces between solids and liquids, or in liquids. Thus, while the theories of Laplace and van der Waals indicate an internal pressure of 10,000 atmospheres in water, and usually from 200 to 4,000 atmospheres in an organic liquid, it has not been found possible to demonstrate experimentally forces greater than 34 atmospheres with water at 24.4° C., 39.5 atmospheres for ethyl alcohol at 22.5, and 72 atmospheres for ether at 17.7°.[9]

The area of the surface in 1 gram of Miss Homfray's charcoal was 1.31×10^6 sq. cm. per gram of charcoal, and in Titoff's charcoal it was 8×10^6, according to estimates made by Williams.[2] Lamb, Wilson, and Chaney[10] have estimated the surface in a gas-mask charcoal as 10^7 sq. cm. per gram, or almost the same as in Titoff's charcoal. In this laboratory Mr. Amando Clemente has been working on the adsorption of vapors at low pressures, and his work seems to indicate an area very well in agreement with that of Lamb, Wilson, and Chaney, but experiments are still incomplete so the final value is uncertain. His work indicates that the adsorptive capacity

of charcoal at low pressures is greatly increased by repeated outgassing or by treating with the vapors or gases to be adsorbed several times between outgassings. Harned has noticed that in the latter way the speed of adsorption is increased, but the effect noticed here is on the equilibrium value. One gram of 750 minute charcoal, according to the ordinary chlorpicrin test, was outgassed, treated with benzene vapor, and then outgassed a second time. The volume of the whole apparatus was 2,200 cu. cm., and was filled at 24° with benzene vapor at a pressure of 1.5 mm. On opening this volume to the *one gram of charcoal*, the pressure fell in 12 hours to 0.00002 mm., or to less than *one seventy thousandth of the initial pressure*. The long time necessary was due to the fact that the equilibrium between the outside and inside of the lumps of charcoal is adjusted very slowly, since the diffusion is very slow. In a similar manner a pressure of 5.13 mm. was reduced to 0.00004 mm. In these experiments the charcoal was also at 24° C., so they illustrate the extremely great effect of the charcoal surface in increasing the life of the molecule[12] on the surface above what it would be on the surface of the liquid. In the second of these two experiments about one-tenth of the surface of the carbon was covered by molecules of benzene, provided the above estimates of the area of the surface are correct. On account of the great differences in the curvature of the surfaces of the pores, the different molecules are held by widely varying forces.

The apparatus first used in this work was similar to that described by Lemon,[11] but it was soon found that more rapid work could be done in an apparatus in which there are no stopcocks. Our work is the first which relates to the volume of different liquids taken up by charcoal. In addition to papers already cited, reference should be made to a paper by Chaney[12] on the activation of carbon, to papers by Langmuir[13] and by Harkins and his co-workers[13] on the theory of surfaces and adsorption, and to papers on adhesion by Harkins.[14] Thanks are due to Dr. Chaney for the preparation for special charcoals, and to the Gibbs Fund of the National Academy of Sciences for a grant which enabled us to purchase the vacuum apparatus.

[1] Titoff, *Zs. physik. Chem.*, **74**, 1910 (641).

[2] Baerwald, *Ann. Physik*, **23**, 1907 (84).

[3] Miss Homfray, *Zs. physik. Chem.*, **74**, 1910 (129).

[4] Bridgman, an extensive series of papers in *Proc. Amer. Acad. Arts Sci.*, especially **49**, 1913 (No. 1).

[5] Richards, *J. Amer. Chem. Soc.*, **38**, 1916 (989).

[6] Williams, *Proc. Roy. Soc. Edinburgh*, **38**, 1917–8 (23); **39**, 1918–9 (48); *Proc. Roy. Soc. London*, A **96**, 1919 (287 and 298).

[7] Langmuir, (*a*) *Met. Chem. Eng.*, **15**, 1916 (468); (*b*) *J. Amer. Chem. Soc.*, **39**, 1917 (1848); (*c*) *Ibid.*, **40**, 1918 (1361).

[8] *J. Russ. Phys. Chem. Soc.*, **47**, 1915 (805).

[9] Donny, *Ann. chim. phys.*, **16**, 1846 (167); Berthelot, *Ibid.*, (3) **30**, 1850 (232); Moser, *Ann. Phys.*, (2) **160**, 1877 (138); Helmholtz, *Ges. Abh.*, **3**, 1887 (264); Worthington,

London Phil. Trans., A **183**, 1892 (355); Meyer, *Zur Kenntnis des negativen Druckes in Flussigkeiten*, Halle, 1911.

[10] Lamb, Wilson, and Chaney, *J. Ind. Eng. Chem.*, **11**, 1919 (420).

[11] Lemon, *Physic. Rev.*, **14**, 1919 (283).

[12] Chaney, *Trans. Amer. Electrochem. Soc.*, 1919 (Advance sheets).

[13] Harkins, Brown, and Davies, *J. Amer. Chem. Soc.*, **39**, 1917 (354); Harkins, Davies, and Clark, *Ibid.*, (541); Harkins and King, *Ibid.*, **41**, 1919 (970); these PROCEEDINGS, **5**, 1919 (152).

[14] Harkins, these PROCEEDINGS, **5**, 1919 (December).

CENTRAL AMERICAN CALENDARS AND THE GREGORIAN DAY

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The day-for-day correlation of the Mayan, Aztecan, and Gregorian calendars depends upon mathematical relations and logical assumptions.

First, as regards the archaic Mayan system of counting time, seen in inscriptions on monuments, the following assumptions are regarded as established:

a. That the permutation cycle of 260 days made by combining 20 days and 13 numbers in sequence was continuously applied to days from a beginning day.

b. That the notational system by which the index number of a day was written down was also continuously applied and that the designation of a day in the permutation and in the notation was constant and determinable.

c. That the *tun* (360 days) and *katun* (7200 days) were not abstract time periods but instead were order values in the notational system and necessarily involved a context of the long count of days of the Mayas just as '06 or '19 necessarily involves a context in the long count of years that distinguishes European chronology.

d. That the Mayan *haab* was a vague year of 365 days divided into 18 long months of 20 days each and one short month of 5 days and that while the true length of the tropical year was known with tolerable accuracy to the Mayas no correction was directly applied to the *haab* count for fear of disorganizing the day count which was the common measure of all astronomical and mathematical cycles.

As regards the records and time counts used by the Mayas of northern Yucatan at the time of the Spanish conquest it is regarded as proven:

a. That an organic contact with the archaic long count was maintained through the orderly succession of *tuns* and *katuns* designated by the name of the day on which they were completed.

b. That a true contact and correlation of the U Kahlay Katunob cycle of the historical summaries in the Books of Chilan Balam and the archaic

long count was affected when the initial series date at Chichen Itza was placed in the earliest occupation of this site in the historical summary. According to this correlation Katun 8 Ahau at the beginning of the historical summary coincides with the round number 9–0–0–0–0, 8 Ahau 13 Ceh, in the long count and the particular Katun 13 Ahau, completed early in the Spanish conquest of Yucatan, coincides with 12–9–0–0–0, 13 Ahau 8 Kankin.

c. That the much-discussed shift in the positions that the days could occupy in the months of the *haab* (whether real or apparent) had no effect on the continuity of day names determined by the permutation cycle and the ancient notation and that 7 Ix 1 Pop of the late Mayan statements must be regarded as equivalent to 7 Ix 2 Pop of the early Mayan statements.

d. That the "year bearer" method of designating the *haab* in northern Yucatan, while frankly at variance with the classical philosophy of counting only completed time units, nevertheless was organically tied into the ancient day count and that a year bearer 7 Ix designated a *haab* beginning with a day 7 Ix 2 Pop in the long count.

e. That the end of Katun 13 Ahau fell during the Spanish conquest of Yucatan in a year 7 Ix according to the following mathematical demonstration:

$$\begin{array}{rl} 12\text{–}8\text{–}14\text{–}4\text{–}14 & 7\ \text{Ix}\ 2\ \text{Pop} \\ \quad 13\text{–}\ 6 & \\ \hline 12\text{–}9\text{–}\ 0\text{–}0\quad 0 & 13\ \text{Ahau}\ 8\ \text{Kankin} \end{array}$$

f. That the year 7 Ix corresponded to the latter part of the European year 1535 and the earlier part of 1536 on reasonable evidence fixing the correlation of several year bearers in the year-bearer cycle (52 × 365 days).

The ground having been laid in this fashion for a correlation of days the complete Mayan year given by Landa is brought into relationship with the long count as follows:

a. This year was one marked by 12 Kan as year bearer and, therefore, corresponded in the current year-bearer cycle to 1553–'54.

b. This initial day of the Landa year, namely, the day 12 Kan 1 Pop in the late Mayan nomenclature or 12 Kan 2 Pop in the ancient nomenclature, equaled 12–9–17–9–4, 12 Kan 2 Pop in the long count and it likewise equaled July 16, 1553, in the Julian Calendar and July 26, 1553, in the Gregorian calendar.

Having made this fundamental correlation it is evident that account must always be taken of the fact that the Mayan *haab* was a 365-day year while the Julian year had an average value of 365.25 days. Thus, if the first day of the year 12 Kan was July 26 in the year 1553, the first day of the year 6 Kan must have fallen on August 3 in 1521.

Among the Aztecs there was no long count of days put down in a fixed

notation or at least no evidence of any such count has come down to us. There was, however, a permutation cycle of 260 days based on 20 names, that show etymological correspondence to the 20-day names of the Mayas, and 13 numbers. The historical records were mostly recorded in a year-bearer system. Structurally the Mexican year began with the month Toxcatl because this was the month that had as its initial day the particular day giving its name to the year.

The day-for-day correlation of the Aztecan calendar and the Gregorian calendar is based on the recorded position of a few days in both counts and on statements of the beginning days of the Aztecan months. These statements have constantly to be corrected as of a definite year owing to the retrogression of the 365-day Aztecan year in relation to the 365.25 day Julian year.

In the correlation as finally effected, the Aztecan year 3 Calli began ostensibly on a day 1 Calli, the first of the month Atlcaualco, but with the significant day 3 Calli as 1 Toxcatl. The day 1 Calli 1 Atlcaualco corresponded to February 12, 1521, Julian calendar, or February 22, Gregorian calendar.

A highly important fact develops when the Mayan and Aztecan calendars are brought together after each has been correlated to the Gregorian day. This fact is the practical identity of the two time counts which has never before been assumed or demonstrated. It should be sufficient to remove any doubts engendered by unavoidable adjudication of evidence where authorities are in conflict.

The Aztecan year bearers, Calli, Tochtli, Acatl, and Tecpatl are equivalent to the Mayan days Akbal, Lamat, Ben, and Eznab, that in the archaic Mayan calendar could occupy the position 1 Pop. But the Yucatan year bearers Kan, Muluc, Ix, and Cauac come one day later than these days. Therefore, the Mayan year bearers, Kan, Muluc, Ix or Cauac, should have numbers one in excess of the equivalent Aztecan year bearers. But it is clear that the Mayan year 6 Kan does not equal an Aztecan year 5 Calli, instead it equals a year 3 Calli. This discrepancy is not fundamental since the two years do not begin at equivalent positions in the tropical year. This initial day 6 Kan 1 Pop of the Mayan year 6 Kan fell on August 3, 1521, and in the Aztecan year 3 Calli found its practical equivalent in the first day of the month Tlaxochimaco that began with 5 Calli on August 1. More exactly 6 Kan equals 6 Cuetzpalin, the second day of the Aztecan month Tlaxochimaco, corresponding to August 2. We find, therefore, that the permutation cycles of the two calendars come within a day of exactly coinciding. The mathematical possibilities involved in this essential agreement would seem to assure the truthfulness of the Mayan correlation.

It is expected that this new possibility of turning Mayan and Mexican dates into the Gregorian calendar will open a new field for investigation.

Central American records on monuments and in codices have long been supposed to contain astronomical statements of eclipses, etc. Furthermore it may be remarked that by this demonstration American history is made more exact than the history of Egypt, Greece, or Rome. For instance, the dedicatory date on Stela 9 at Copan corresponds to March 31, 304 A.D., in the backward projection of our present Gregorian calendar. The earlier artistic classification of the present writer, and the general *katun* correlation of Morley, were correct within a very few years.

The data in full will appear in the *Anthropological Papers of the American Museum of Natural History.*

THE TORSIONAL MAGNETIC ENERGY ABSORPTION OF AN IRON CONDUCTOR[1]

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1. *Apparatus.*—The relations of torsion and magnetization have been studied by Wiedemann, Auerbach and many others since, chiefly in longitudinal fields. The torsion effect produced by a circular field is very small and difficult to ascertain. I, therefore, thought it of interest to make some measurements of this kind, using the displacement interferometer and achromatic fringes. The results were very definite and would easily have admitted of higher precision. The apparatus is shown in figure 1, where AB is a thin, low carbon steel tube, effectively 55 cm. long, having an average diameter of 0.875 cm., and walls 0.076 cm. thick.

The tube is firmly clutched below by a clamp, but free above. It carries the mirror mm' which is a strip of thin plate glass, silvered and slightly adjustable about a vertical and horizontal axis. The ends receive the component rays of the interferometer, so that any slight rotation of mm' about the vertical axis is at once registered by the displacement of fringes. Finally a strong electric current may be passed through the length of the tube, entering at A and leaving by the mercury cup C. The current must be reversible at pleasure

2. *Observations.*—The fringes are displaced (i.e., the tube receives magnetic set) immediately after closing the circuit. Closing it any number of times thereafter is ineffective to the fraction of a fringe. There is practically no temporary effect. On reversing the current, the fringes are markedly displaced in the opposite direction, again to hold the new position, however often the current is made and broken thereafter.

To obtain a temporary effect I surrounded the AB with a massive iron tube, about 6 inches long and 2 inches in diameter, clamped at the top B (bell-like) but otherwise free from it. Even now, with currents up to

20 amperes, I observed no temporary effect in excess of the quiver of the fringes.

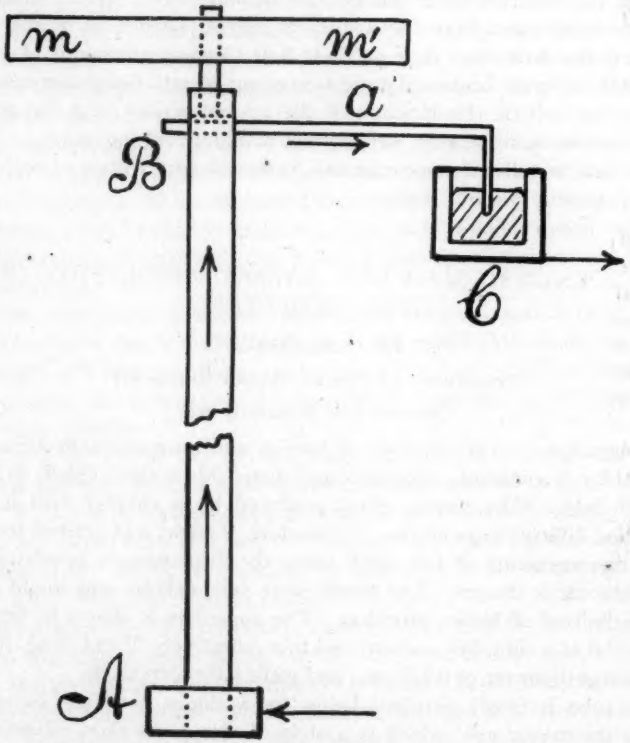

FIG. 1

The following data were obtained for the fringe displacement ΔN, showing the permanent effect of reversal of current:

Current,	3 Am.	ΔN = ?
	10 Am.	0.00031 cm.
	20 Am.	0.00065 cm.

Below 3 amperes I was unable to observe a displacement. For larger currents the twist increases proportionally to the current passing the tube. It is probable that here, as in similar cases in magnetization, fields below a certain small value are ineffective, as though there were static friction.

A further observation is to be made: If a certain magnetic set is produced by a stronger current (say, 20 amperes), then a weaker current (say, 10 amperes) is unable to modify it, provided both currents are in the same direction. If this weaker current is reversed, the change of twist

corresponding to the current will appear. The absolute value of the set thus depends upon the past history of the iron, however varied this may have been, with the understanding that the set produced by the maximum current in either direction is characteristic of the strength of that current. Differential values, in other words, remain the same.

3. *Data.*—Finally the numerical equivalents of the observations made may be stated. The elastic torsional coefficient for a tube of the dimensions given may be computed with the usual equation, using the differential form $dT/dr = 2\pi nr^3\theta/l$ (mean radius r and length l) and taking the rigidity as $n = 8.2 \times 10^{11}$. If T is the torque corresponding to the twist of θ radians, the relation was found to be

$$T = 10^9 \times 4.7\theta.$$

On the interferometer, if the breadth of ray parallelogram is $b = 10$ cm. and $\Delta\theta$ is the rotation of the mirror mm' around a vertical axis, corresponding to the displacement of mirror ΔN (the mirror being at $i = 45°$ to the rays), the relation will be, since $\Delta\theta = \Delta N \cos i/b$,

$$\Delta\theta = 0.071\,\Delta N.$$

Hence, if we assume that the resistance to magnetic set is the same as the elastic resistance for the same twist $\Delta\theta$, the above values of ΔN will correspond to the following data:

Current	$\Delta N \times 10^4$	$T \times 10^{-5}$	E	E/vol.
10 Am.	31	1.03	1.13	.10
20 Am.	65	2.16	4.97	.43

The energy, E, potentialized by the magnetic set is computed as $T\Delta\theta/2$. From the volume of iron in the tube, 11.5 cm^3., the data of the last column follow.

My conception of this phenomenon is that of two concentric circular fields in opposite directions, one within the other on the outside of the tube, introducing a rather intense vortex sheet in the thin walls of the tube, in which the circular fields terminate.

4. *Longitudinal Field.*—The longitudinal strain produced by a longitudinal field is well known. The question may be asked whether in this case, in a free iron bar, there is any corresponding torsion. This was easily answered by slipping a helix over the steel tube. Feeding it with I amperes, the micrometer displacement ΔN was successively

$I =$	1.5	4.5	9.4	1.5	Am.
$10^6 \times \Delta N =$	15	10	10	5	Cm.

This means, no doubt, that the residual torsion left by the last experiments is being eliminated.

[1] Advance note from a report to the Carnegie Institution of Washington, D. C.

THE ADJUSTMENT TO THE BAROMETER OF THE HEMATO-RESPIRATORY FUNCTIONS IN MAN

BY YANDELL HENDERSON

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Communicated by L. B. Mendel. Read before the Academy, November 10, 1919

It is well known that persons living at considerable elevations—such as Colorado, the cities in the Andes, et cetera—exhibit distinct functional adjustments. The amount of hemoglobin per unit volume of blood is increased, and a larger volume of air is breathed per unit mass of oxygen absorbed and CO_2 eliminated.

These are functional adjustments and not merely immediate compensations; for they are developed slowly through days or weeks, and the functions return to sea level values only very gradually. Thus, to illustrate by a single simple test, a man on Pike's Peak, who is acclimated to the altitude, can hold his breath for a much shorter time than when living at sea level. But on descending from the Peak, and during the first few hours thereafter, he can hold it scarcely longer than at the summit.

There is clear evidence that this condition and the increase of breathing are due to a decreased amount of alkali, chiefly $NaHCO_3$, in the blood. By the now well-known equation of L. J. Henderson,

$$\frac{H_2CO_3}{NaHCO_3} \times K = C_H,$$

it is evident that, if respiration is to maintain the same C_H in the blood at an altitude that it does at sea level, the amount of CO_2 in solution in the blood must be reduced in proportion to the alkali. This is accomplished by an inversely proportional alteration, that is, an increase, of breathing.

It is generally supposed that under oxygen deficiency acids are produced in the tissues and retained in the blood, and that the alkali is thus neutralized and then eliminated through the urine.

Experiments on dogs by Dr. H. W. Haggard and myself, however, show that the processes involved are in many respects exactly the opposite of this supposition. Our experiments demonstrate that, before any considerable amount of alkali is lost, an abnormally large amount of CO_2 is eliminated by the excessive breathing induced by a lowered oxygen pressure in the air breathed. Then alkali passes out of the blood to compensate this alkalosis.

Thus the process is exactly the opposite of that occurring in other experiments which we have performed, in which acid was administered intravenously, and in which, therefore, the alkali was lowered first and the CO_2 in solution was lowered only secondarily.[1] Under low oxygen the lowering of the dissolved $CO_2(H_2CO_3)$ is primary, and that of the alkali secondary.

From these facts and from closely similar observations on aviators[2] during the war, it appears highly probable that in normal persons the blood alkali is controlled by the dissolved CO_2: more or less alkali being called into use in the blood to satisfy the equation above quoted, and to keep the C_H of the blood constant. The amount of dissolved CO_2 in the blood is controlled by the pulmonary ventilation; and fundamentally the ventilation is adjusted to the oxygen partial pressure of the air at the altitude at which the person lives.

Thus, as data from the report of the Pike's Peak expedition[3] tend to confirm, the partial pressure of oxygen in the lungs, the alveolar CO_2, the $CO_2(H_2CO_3)$ dissolved in the blood, and the amount of the blood alkali (the so-called "alkaline reserve"), each multiplied by a constant of its own, tend to vary in direct proportion to the mean barometer, minus the water vapor tension of the pulmonary air (about 45 mm.) at all altitudes.

[1] Haggard, H. W., and Henderson, Yandell, *J. Biol. Chem.*, **39**, No. 1, August, 1919 (163–261).

[2] Henderson, Yandell, *Science, New York*, N. S., **49**, No. 1271, May 9, 1919 (431–441).

[3] Douglas, Haldane, Henderson, and Schneider, *London Phil. Trans. Roy. Soc.*, B. **203**, 1913 (310).

A STUDY OF ABSORPTION SPECTRA WITH THE ELECTRIC FURNACE

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Communicated by G. E. Hale, December 9, 1919

The tube resistance furnace has found a place as a useful light-source in spectroscopic work, but thus far it has been used mainly for the production of emission spectra. The long column of vapor, whose temperature can be controlled, offers interesting possibilities, however, in the field of absorption phenomena. In the experiments to be described, the continuous background was supplied by a plug of graphite placed in the center of the furnace tube, the heated portion of which was 20 cm. long and 12.5 mm. internal diameter. A close approach to black-body conditions is thus obtained, and the emission of the plugged tube is stronger than that of the metallic vapor filling the tube. An absorption spectrum results, which, by simply removing the plug, may be compared with the emission spectrum given by the vapor at the same temperature.

It is known from observations of reversed emission lines that in a given range of spectrum, some lines are more subject to reversal than others. The present experiments have shown this to result from a close connection between the tendency of a line to reverse and the two factors which enter into the classification of lines in furnace spectra, viz., the temperature at which a line is first radiated and its response to increase of temperature.

The phenomena may be briefly described by saying that when a temperature is reached sufficiently high to produce an absorption spectrum, the lines appearing are those of low-temperature class. As the temperature is raised, lines of successively higher classes appear. The lines of low-temperature class thus show the largest degree of absorbing power. At a given temperature, the absorption spectrum shows fewer lines than are given by the emission spectrum at the same temperature. The absent lines are of the higher temperature classes, which the vapor is able to emit, but which have relatively low absorbing power. For the iron and titanium spectra, the absorption spectrum is very similar to that given in emission at a temperature about 400° lower. As lines which are strong in the furnace and faint in the arc are usually lines of large absorptive power, the difference between the arc and the dark-line furnace spectrum is very striking.

The dependence of absorptive power on temperature class was well brought out by placing the graphite plug beyond the center of the tube away from the spectrograph, so that some of the metallic vapor was hotter than the plug. It was then possible to obtain emission and absorption lines at the same time. The high-temperature lines appeared in emission, while the plug was still hot enough to cause those of low-temperature class to show as absorption lines.

Lines which are being emitted by a vapor may fail to appear in absorption owing either to a low absorptive power and consequent quenching by the continuous spectrum, or to a balancing of emission and absorption which may occur when the continuous background is reduced in temperature so that its emission is of about the same strength as that from the metallic vapor. This latter condition was produced in the furnace by withdrawing the plug nearly to the end of the tube. Lines produced by the vapor in the central portion were then frequently neutralized by the balanced emission and absorption and were not to be seen. In this way a line may seem to be totally absent when in reality it is being strongly radiated by the vapor.

A method of producing absorption spectra without the use of a plug may be mentioned in this connection. When the furnace is operated in the usual way, with a metallic powder or salt in the open tube, the emission spectrum increases in intensity and number of lines as the temperature is raised, until it compares in richness with that of the arc. A still higher temperature causes a rapid increase in a continuous ground, which is probably due in part to the long column of dense metallic and carbon vapor and partly to light from the walls of the tube reflected by the vapor particles. This obliterates the emission lines and we have an absorption spectrum consisting of the lines which in the high-temperature emission spectrum were self-reversed. In general these are low-temperature lines, although they result from a high-temperature condition. This phenomenon may

occur with the furnace in vacuo, so that the continuous spectrum cannot be regarded as resulting from a high-pressure condition. The possibility of producing an absorption spectrum accompanied by the suppression of many lines which are being emitted strongly at this temperature must be considered when dealing with an extended mass of vapor.

A STUDY OF THE EFFECT OF A MAGNETIC FIELD ON ELECTRIC FURNACE SPECTRA

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Communicated by G. E. Hale, December 9, 1919

Investigations on the splitting of spectrum lines by the magnetic field have employed, except in rare instances, the electric spark as the source of light. It has proved impracticable to maintain an arc between the poles of a magnet, though an apparatus giving a succession of flashes has been employed. The flame, because of its weak luminosity, has but limited usefulness. The electric furnace, if its size does not prevent its use in the magnetic field, will evidently do work not at present taken care of. While the furnace does not give the enhanced lines peculiar to the spark, the other lines shown by the arc and spark occur for the most part in the furnace spectrum. In addition, the furnace is found to show a large number of lines which are produced only with great difficulty by either the arc or the spark, and for which we have as yet no data as to their magnetic separation. A further advantage over the spark for the lines common to both is the extreme sharpness of furnace lines when the apparatus is enclosed in a vacuum chamber, a feature which should add materially to the definition of the Zeeman components.

Pending the construction of a more powerful apparatus, a simple tube furnace was arranged for use in a magnetic field. A graphite tube, 10 cm. long, was placed axially between the poles of a Weiss electro-magnet. The jacket enclosing the tube and the contact blocks at the ends were water-cooled. A field of 6500 gausses separated the π components of most lines sufficiently to permit measurements of fair accuracy and to show the characteristic features of the source. The spectra of iron and vanadium received the chief attention, and measurements were made for a considerable number of lines having well-defined components. A comparison of lines common to furnace and spark showed no difference either in the number and arrangement of components, or in their separation in the two sources, the very different excitation in the two cases appearing to have no effect on the magnetic characteristics. The furnace and spark can thus be used to supplement each other in studying the magnetic behavior of all classes of lines. As was expected, separations were obtained for

many characteristic furnace lines which the spark emits very faintly. An outstanding feature of these lines for the iron spectrum is a prevailing large separation and simple triplet structure. Lines of this class are often of special interest in the study of sun-spot spectra.

The furnace offers unique facilities for the production of the inverse Zeeman effect when a plug is placed in the tube. The absorption spectra resulting from this arrangement were discussed in the preceding communication. An extended study was made of the magnetic components given in absorption by this method. No difference was observed as to character or magnitude of separation as compared with the effects for the emission spectrum. A means of direct comparison with the magnetic effects for absorption lines in the solar spectrum is thus afforded, which may be expected to be very useful in tests as to polarization and other features at various angles to the lines of force.

SELECTIVE FERTILIZATION IN POLLEN MIXTURES

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Communicated by T. B. Osborne, Read before the Academy, November 10, 1919

The fact of self-sterility or self-impotency is well established in many species of plants and in at least one family of animals. It is also believed that even in the normal condition of self-fertility the germ cells from different, unrelated individuals in some cases are more efficient in accomplishing fertilization than the germ cells from the same or similar individuals. Statements to this effect are made in text books on biology.

A simple method of accurately testing this assumption is available in the use of pollen mixtures which carry such inherited characters that the different kinds of seeds resulting from the pollinations can be distinguished. By taking pollen from two distinct types of maize, designated A and B, in approximately equal quantities, thoroughly mixing, and applying the mixture to the plants which furnish the pollen, it is possible to obtain and to separate the two kinds of seeds on each plant. On the A plants the seeds are $A \times A$ self-fertilized and $A \times B$ cross-fertilized. Similarly, on the B plants the seeds resulting from the mixture are $B \times A$ cross-fertilized, and $B \times B$ self-fertilized. The numbers of individuals in each class form a proportion such that the $A \times A$ seeds are to the $A \times B$ seeds (produced on A plants) as the $B \times A$ seeds are to the $B \times B$ seeds (produced on B plants). The end terms of this proportion represent self-fertilized, while the middle terms represent cross-fertilized seeds. If fertilization takes place at random the numbers form a perfect proportion, irrespective of the relative amounts of functional pollen present in the mixture and independent of the total number of seeds obtained from

either the *A* or the *B* plants. If there is a deviation from a perfect proportion, this will be either in favor of cross-fertilization or self-fertilization.

RESULTS OF MIXED POLLINATIONS GIVING THE TOTAL NUMBER OF SEEDS, AND THE NUMBERS IN EACH CLASS FORMING PROPORTIONS, THE DEVIATIONS OF WHICH EXPRESSED AS PER CENT, FROM THE CLOSEST TRUE PROPORTIONS, ARE LARGELY IN FAVOR OF THE PLANT'S OWN KIND OF POLLEN. *P* IS THE PROBABILITY THAT THE DEVIATIONS ARE DUE TO THE DIFFERENCES OF RANDOM SAMPLING

POLLEN MIXTURE NUMBER	TOTAL NUMBER OF SEEDS	NUMBER OF SEEDS IN EACH CLASS				DEVIATION FROM TRUE PROPORTION, PER CENT	X^2	*P*
		A × *A*	*A* × *B*	*B* × *A*	*B* × *B*			
1	3430	1738	46	1602	44	+0.045	0.027	0.994
2	5636	2133	145	3080	278	+0.955	7.572	0.063
3	1362	229	14	770	349	+12.715	146.196	0.000
4	3344	710	126	1856	652	+5.465	61.203	0.000
5	1956	589	6	1290	71	+2.105	28.718	0.000
6	424	40	71	187	126	−11.850	23.858	0.000
7	3459	23	89	1507	1840	−12.245	235.357	0.000
8	7783	2185	956	2619	2023	+6.570	144.108	0.000
9	8729	2550	1288	2922	1969	+3.350	42.061	0.000
10	5408	1084	1154	997	2173	+8.495	162.687	0.000
11	3314	448	264	1505	1097	+2.540	8.937	0.030
12	3561	1724	719	749	369	+1.790	5.313	0.053
13	736	185	391	95	65	−13.625	55.051	0.000
14	792	424	150	156	62	+1.155	0.533	0.894
15	3168	2609	47	14	498	+47.750	2889.561	0.000
16	2224	723	8	74	1419	+46.975	1965.981	0.000
17	1410	1303	3	4	100	+47.960	1298.993	0.000
18	1599	4	21	1	1573	+7.970	137.532	0.000
19	2606	528	392	343	1343	+18.525	376.394	0.000
20	2753	897	77	1174	605	+13.050	283.002	0.000
	63694							

One great advantage of using endosperm characters in this way is that the several kinds of seed develop under nearly as favorable environmental conditions as it is possible to obtain, so that selective elimination of zygotes, which may favor one class more than another, is reduced to a minimum. In those plants in which the cross-fertilized and self-fertilized progeny cannot be distinguished until they are grown to maturity there is considerable likelihood that unequal germination and differential viability will tend to favor cross-fertilization. Animals are subject to the same objection as material for investigating this problem.

The method of mixed pollination in reciprocal applications is the simplest means of accurately testing the efficiency of two kinds of pollen in competition with each other. It is impossible to know definitely the relative

numbers of the two kinds of fertilizing elements present in a mixture. Even if it were possible to obtain equivalent amounts of pollen or seminal fluids there would be no way of knowing the ratio of the two kinds of effective germ cells, since in many species such cells rapidly lose their viability.

In many experiments performed with maize, pollen was collected from a number of plants of two distinct but uniform types of plants. Approximately equal quantities of each kind of pollen were taken, thoroughly mixed by shaking in a bag, and applied to a number of plants of each of the two kinds supplying the pollen. The aim was to have from 1000 to 2000 seeds in each of the two parts of the proportion. Twenty such mixed pollinations were made, using many different types of maize, and altogether there resulted 63,694 seeds. These have been classified, counted, and a sample of each lot grown to test the accuracy of separation, and the proportions have been calculated as percentages. See table 1. Seventeen of the twenty show a deviation in favor of the plant's own kind of pollen, while only three show the reverse effect. Of the 17 experiments which indicate a prepotency of pollen on the stigmas of the plants by which it was produced, 2 are not significant when compared with the deviations expected in sampling. In the remaining 15 the deviations are so large that there can be no question that in maize there is a pronounced preference of the plant for its own kind of pollen, even though the foreign pollen is perfectly capable of accomplishing fertilization when not in competition.

Similar experiments have been carried out with another plant, the tomato. Two pollen mixtures were made, utilizing characters by which the seedlings could be separated. As with maize, the results give a deviation favoring the familiar pollen. However, the number of plants obtained was not large and classification was not so sure as in the experiments with maize.

Taking the results from maize alone, magnifying the experimental error to its fullest extent, giving due allowance to differential viability, and taking into consideration the differences arising from random sampling, the conclusion is inevasible that in this species at least there is a definite receptiveness of the plant to its own kind of pollen. This is notable in view of the great advantages which hybrid vigor gives immediately to the cross-fertilized seeds and the plants grown from them. The weight of cross-pollinated seed is increased as much as 50% in some cases. Both the embryo and endosperm are larger, the seeds have a higher specific gravity, and they mature faster, as shown by their lower water content at the end of the growing period. The increase in weight, expressed as per cent, permits a comparative estimation of the amount of heterosis shown by the various combinations involving different materials. There is a significant correlation between the amount of heterosis and the prefer-

ence shown by the plant for its own pollen. Since heterosis is roughly proportional to germinal diversity, the greater the genetic differences there are the greater is the handicap placed upon the pollen when competing with pollen from the plants on which it is to act. This is a remarkable result, because *in proportion as the cross-fertilization benefits the progeny the less effective are the germ cells in accomplishing fertilization.*

It should be clearly kept in mind that the selective action shown in pollen mixtures is not the same as a differential potency of unlike gametes produced by one individual. In the latter case there is no positive proof that such an effect is ever obtained, where the different gametes are all viable, and in most cases there certainly is no such action.

It has been found that the same selective action is shown when first generation hybrids are paired as when strains which have been long inbred are used. In other words, the effect is apparent, whether the plants have a long line of similar ancestors back of them or whether their immediate parents are diverse. It is also shown both in plants of weak growth or of full vigor, and whether the gametes of either type or both are alike among themselves or are exceedingly diverse in the hereditary factors which they carry. The only feature in common is that the cytoplasm is alike for all the germ cells of one plant, and this cytoplasm, in self-fertilization, is the same in which the pollen fulfils its function. This indicates that the unequal fertilizing ability is governed by the rate of pollen tube growth, although it may be determined after the male gametes are brought to the egg.

There is current in biological literature the assumption that heterogeneity in protoplasmic structure is favorable to developmental efficiency. This idea has been proposed again and again and applied in many different ways. Stated in general terms, it implies that the union of diverse elements and the resulting lack of balance stimulates growth. This is a heritage from Darwinism, and the writer believes that it is founded upon fallacious reasoning and is not supported by the facts.

The hypothesis has been used in theories of rejuvenation, explanations of hybrid vigor, and speculations concerning selective fertilization. The necessity for sexual reproduction at some time to maintain organisms reproducing asexually is no longer admitted. That the process of forming gametes which reunite to make a new individual may bring about a reorganization of the protoplasm with elimination of waste products resulting in increased growth is easily conceivable, but the significance of such a procedure is not necessarily to be found in the bringing together of unlike elements. The vigor of hybridization has now been put on a basis of pure inheritance, and the physiological stimulation hypothesis is no longer needed. Homozygous factor combinations, according to present theory, are more efficient than heterozygous combinations of the same factors. It now seems that self-prepotency, except in those cases where a definite

process has been developed to prevent self-fertilization, indicates that unlikeness instead of favoring fertilization is a hindrance.

So valuable have been the evolutionary advantages of sexual reproduction in increasing variability that many contrivances have been perfected to insure the fulfilment of the function responsible for its creation. Self-sterility or self-impotency is one of the many special adaptations which serve this purpose. The evidence for selective fertilization favoring organisms of the same type, or self-prepotency, is limited just now to one or possibly two species. Will it not be strange to find it so restricted? Is it not more likely to be a general phenomenon manifested in some degree by many organisms? Even in those cases where cross-fertilization is made imperative by a physiological impediment to self-fertilization the same tendency may operate although overwhelmed by the special adaptation. One cannot insist that such is the case, with the evidence isolated as it is at present. Neither is it maintained that the reaction of the cytoplasm of the pollen tubes with the tissues of the host, preceding fertilization, has any relation with the processes which go on within the cells after fertilization. But the prepotency of germ cells acting upon the same or similar individuals which produced them is another indication that homogeneity, likeness, similarity, familiarity, or however it may be described, in protoplasmic structure is consistent with and favorable to the highest developmental efficiency.

GROUPS GENERATED BY TWO OPERATORS, s_1, s_2, WHICH SATISFY THE CONDITIONS $s_1^m = s_2^n$, $(s_1s_2)^k = 1$, $s_1s_2 = s_2s_1$

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Communicated by E. H. Moore, December 6, 1919

W. R. Hamilton observed, in 1856, that the groups of movements of the five Platonic solids may be defined by means of equations of the form

$$s_1^m = s_2^n = (s_1s_2)^k = 1.$$

Various generalizations of these groups were obtained during recent years by means of equations of the form

$$s_1^m = s_2^n, (s_1s_2)^k = 1.$$

In both of these cases only a few special values of m, n, k were considered. On the contrary, general values of m, n, k are considered in the present note, but an additional condition is imposed on s_1, s_2; viz., the condition that they shall be commutative operators. Hence all the groups generated by these two operators are abelian.

The main result obtained in this note may be stated as follows: *If two commutative operators, s_1 and s_2, satisfy the conditions $s_1^m = s_2^n$, $(s_1s_2)^k = 1$*

but are not restricted otherwise they generate the direct product of two cyclic groups of orders $(m + n)k/d$ *and* d, *respectively,* d *being the highest common factor of* m, n, k. In particular, a necessary and sufficient condition that the group G generated by s_1 and s_2 is cyclic is that m, n, k have no common factor greater than unity. For instance, the cyclic group of order 75 is determined by two commutative operators which satisfy the equations

$$s_1^6 = s_2^9, (s_1 s_2)^5 = 1.$$

This group is also determined by $s_1^{10} = s_2^{15}, (s_1 s_2)^8 = 1$, etc.

It may first be noted that G is always cyclic when m and n are relatively prime. In fact, when this condition is satisfied and p is any prime number which divides m then the Sylow subgroup of order p^α contained in the group generated by s_1 includes the Sylow subgroup of order p^β contained in the group generated by s_2, and $\alpha > \beta$ when k is divisible by p. When k is not divisible by p then $\alpha = \beta = 0$. Hence it results that the Sylow subgroups of G whose orders are not prime to both of the numbers m and n are cyclic whenever m and n are relatively prime. The other Sylow subgroups of G must also be cyclic since they are generated by s_1^m. This proves that G is cyclic whenever m and n are relatively prime.

When m and n are not relatively prime let d_1 represent their highest common factor. Just as before it follows that the Sylow subgroups of G whose orders are prime to d_1 are cyclic, and those whose orders are not prime to d_1 must also be cyclic when k is prime to d_1 since the generator of such a Sylow subgroup in the group generated by s_1 must be the inverse of such a subgroup in the group generated by s_2. It has, therefore, been proved that a sufficient condition that G be cyclic is that the three numbers m, n, k have no common factor greater than unity.

To prove that the order of G is $(m + n)k$ when this condition is satisfied it is only necessary to prove that the orders of s_1 and s_2 divide this number and that G contains at least one operator whose order is equal to this number. The former of these facts results directly from the following equations:

$$s_1^k = s_2^{-k}, s_1^{km} = s_2^{-km} = s_2^{kn}, s_2^{k(m+n)} = 1 = s_1^{k(m+n)}$$

To establish the latter fact it may be noted that when p^α, $\alpha > 0$, is the highest power of p which divides k, and p^β is the highest power of p which divides $m + n$, then we let t_1 represent a constituent of s_1 of order $p^{\alpha+\beta}$ and $t_1^{-1+lp^\beta}$ the corresponding constituent of s_2, where l is so chosen that $t_1^n = t_1^{-n+nlp^\beta}$. As n is prime to p, the product nl represents all the residues prime to p mod p^α, and hence it follows that G involves the cyclic subgroup of order $p^{\alpha+\beta}$.

It remains only to prove that when q^γ is the highest power of the prime number q which divides $m + n$, q being prime to k, G involves a cyclic subgroup of order q^γ. Let t_2 be a generator of such a group. As $t_2^{m+n} = 1$ it follows that $t_2^m = (t_2^{-1})^n$, and hence s_1 may be supposed to have

t_2 as its constituent whose order is a power of q while s_2 has t_2^{-1} as its corresponding constituent. It has, therefore, been proved that when m, n, k do not have a highest common factor greater than unity, and s_1 and s_2 are commutative, the largest group which they can generate subject to the condition $s_1^m = s_2^n$, $(s_1 s_2)^k = 1$ is the cyclic group of order $(m + n)k$.

When the highest common factor of m, n, k is $d > 1$ the Sylow subgroups of G whose orders are prime to d are seen to be cyclic just as in the preceding case. The order of every operator in such a group must divide $(m + n)k/d$, since $s_1^k = s_2^{-k}$ and hence $s_1^{\frac{km}{d}} = s_2^{-\frac{km}{d}} = s_2^{\frac{nk}{d}}$, $s_1^{-\frac{kn}{d}} = s_1^{\frac{km}{d}}$. Let r be any prime divisor of d and let r^e be the highest power of r which divides d while $r^{\theta+e}$ is the highest power of r which divides $(m + n)k$. From the preceding proof it follows that G involves an operator t_3 of order r^θ since such an operator generates a Sylow subgroup of the group determined by the equations

$$s_3^m = s_4^n, \quad (s_3 s_4)^{k/d} = 1.$$

Suppose that s_3 generates t_3. If an operator which generates the Sylow subgroup whose order is a power of r contained in the group generated by s_4 is multiplied by an independent operator of order r^e this product and s_3 satisfy the conditions

$$s_1^m = s_2^n, \quad (s_1 s_2)^k = 1.$$

Hence it results that the Sylow subgroup of G whose order is a power of r involves two independent operators of orders r^θ and r^e, respectively. To complete a proof of the theorem under consideration it is, therefore, only necessary to establish the fact that $r^{\theta+e}$ is the order of a Sylow subgroup of G.

When k is not divisible by r^{e+1} this fact is evident since the order of neither of the two operators s_1, s_2 is divisible by $r^{\theta+1}$ and the order of at least one of them is divisible by r^θ. If the order of the Sylow subgroup in question would exceed $r^{\theta+e}$ the order of the product of these two operators would have to be divisible by r^{e+1}. When k is divisible by r^{e+1} at least one of the two numbers m, n is not divisible by r^{e+1}. Suppose that m is not divisible by r^{e+1}. Hence the order of the Sylow subgroup in question cannot exceed r^e times the order of the corresponding Sylow subgroup in the group generated by s_2. This completes a proof of the theorem in italics announced in the second paragraph of this note.

This theorem is useful in the study of the generalized groups of the regular polyhedrons as may be seen from the fact that if two commutative operators satisfy the equations $s_1^3 = s_2^4$, $(s_1 s_2)^2 = 1$, they generate the cyclic group of order 14 or one of its subgroups. This explains why the largest non-abelian group, which is generated by two operators satisfying these conditions, is a direct product of the group of order 7 and some other group (Miller, Blichfeldt, Dickson, *Finite Groups*, 1916, p. 157).

Mr. W. E. Edington, graduate student in the University of Illinois, directed my attention to the desirability of a study of the given general equations as regards commutative operators with a view to simplifying the treatment of the generalized polyhedron groups.

MODEL OF THE LINKAGE SYSTEM OF ELEVEN SECOND CHROMOSOME GENES OF DROSOPHILA

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In previous papers[1] reasons have been given for thinking the spatial relations of genes to be three-dimensional rather than linear as assumed in the hypothesis of Morgan and his colleagues. In particular it has been shown that in models made to represent the spatial relations of the genes in the sex chromosomes of two different species of Drosophila, using the original unmodified data, as reported by Morgan and Bridges[2] and by Metz,[3] the arrangement is apparently three-dimensional. Recently data have become available for modeling in a similar way the interrelations of the genes in the so-called "second chromosome" of Drosophila ampelophila.[4] Two views of such a model are seen in figures 1 and 2. The model shows the linkage relations of eleven genes, those for which the data are most complete and reliable according to Bridges and Morgan. The data are taken from table 140 of the publication mentioned. Each gene is represented in the model by a small ring of wire and it is connected with another gene by a wire as long in inches as is the cross-over value, in per cent, between the two genes joined by the wire. In the figures the model is suspended by S, the view shown in figure 2 being taken at right angles to that shown in figure 1. The eleven genes represented in the model are as follows:

S, star (0.0)	*vg*, vestigial (65.0)
Sk, streak (15.4)	*c*, curved (73.5)
d, dachs (29.0)	*px*, plexus (96.2)
b, black (46.5)	*a*, arc (98.4)
pr, purple (52.7)	*sp*, speck (105.1)
	mr, morula (106.3)

The numbers in parentheses indicate the position of each gene in the linear "map" of Bridges and Morgan (p. 127). It will be observed that seven of the genes in this list are represented in the "map" at distances greater than 50 from star, which lies at 0. In the previous publications already cited, I have maintained that since cross-over percentages of 50 or more have not in any case been observed and are logically impossible as a result of linkage, map distances should not be shown in

excess of 50. But further consideration of the matter leads me to withdraw this objection. If the arrangement of the genes is really linear, as assumed by Morgan, then double crossing-over is a sufficient explanation of why cross-over percentages do not increase as fast as map distances. But double crossing-over is the questionable phenomenon which need not be assumed if the arrangement is non-linear. Hence, by constructing models such as are shown in figures 1 and 2, I have attempted to ascertain

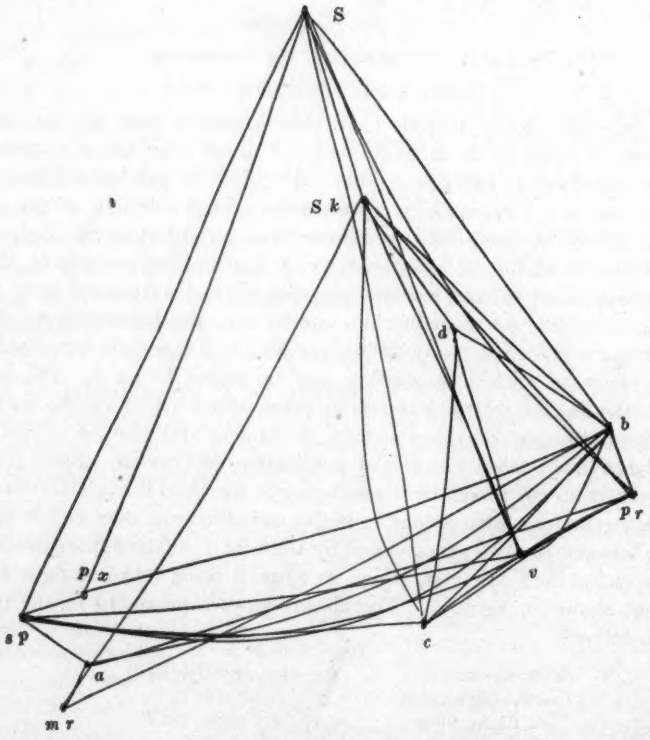

FIG. 1

whether a workable system could be found which was able to dispense with double cross-overs, assuming a non-linear arrangement. It seemed to me that such was the case even after the model seen in figures 1 and 2 had been constructed. I next examined the data given by Gowen[5] for the linkage relations of eight genes of the "third chromosome" of Drosophila. On constructing a model to show the spatial relations of the genes, without assuming the arrangement to be linear, and without making any allowances for double or triple crossing-over, I obtained a figure strikingly similar to

the model of the sex-linked group of genes. The eight genes fell into a curved band lying nearly in one plane, the model being quite flat as viewed

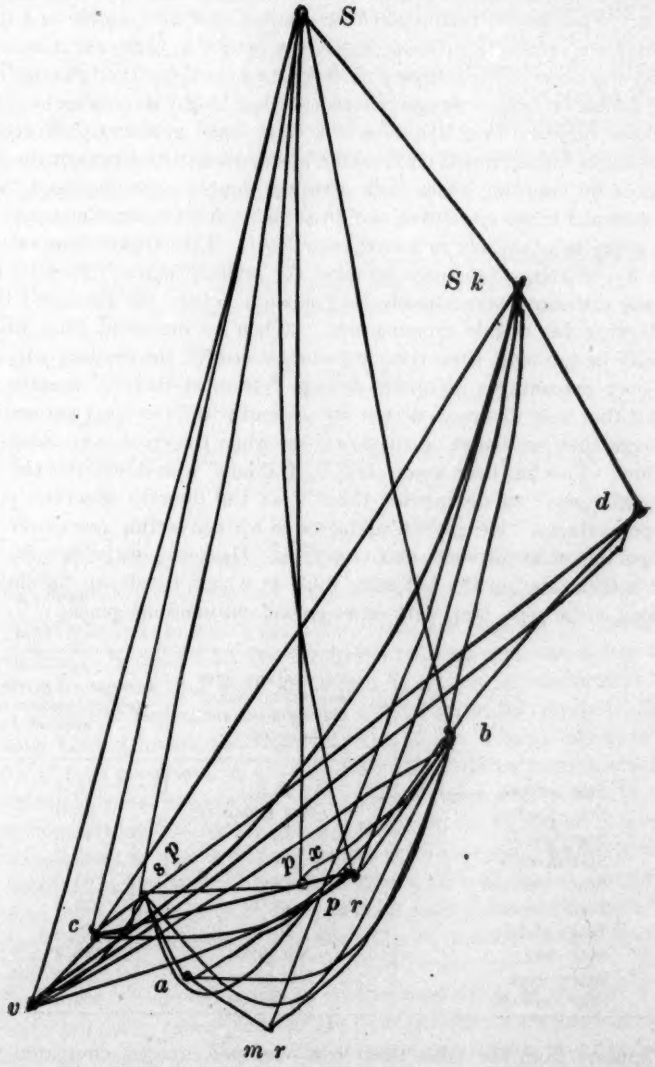

FIG. 2

edgewise. The figure indeed is, as Sturtevant, Bridges and Morgan[6] said concerning my model of the sex-chromosome linkage system, "capable

of reduction to a curved line lying in one plane." Obviously the arrangement approaches the linear, but it is curvilinear rather than rectilinear as shown in the chromosome maps. But if we grant that the arrangement is in any sense linear, then it must be granted also that double and triple crossing-over are likely to occur, indeed we cannot in that case reasonably explain the observed regrouping of characters on any other assumptions. But if double crossing-over occurs oftenest when long distances are involved, it follows that the long distances will have been apparently shortened. If now in the model based on Gowen's observations, we lengthen the long distances by counting twice each assumed double cross-over and thrice each assumed triple cross-over, we do in fact obtain a distribution of the eight genes substantially in a *rectilinear band*. This strongly supports the linear hypothesis. Yet there remains the serious logical difficulty that the long distances were already long enough before we increased them by allowing for double crossing-over. When so increased they will of necessity be too long, since they will now exceed 50, the limiting value for cross-over percentages involving linkage. It must then be frankly recognized that map distances do not correspond with cross-over percentages (although they are based on them) except when the cross-over values are very low. This has been made clear by Haldane[7] who designates the map units "morgans" to distinguish them from the directly observed cross-over percentages. He gives a useful table for converting cross-over percentages into map-distances and vice versa. How widely the two may diverge is illustrated in the following table in which are shown the linkage relations of the gene, star, with other second chromosome genes.

	OBSERVED CROSS-OVER PERCENTAGE (TABLE 140, BRIDGES AND MORGAN)	LINEAR MAP DISTANCE (FIG. 72, BRIDGES AND MORGAN)
Star—streak	15.9	15.4
Star—dachs	Not given	29.0
Star—black	37.9	46.5
Star—purple	43.7	52.7
Star—vestigial	43.3	65.0
Star—curved	45.9	73.5
Star—plexus	46.7	96.2
Star—arc	Not given	98.4
Star—speck	Not given	105.1
Star—morula	Not given	106.3

It appears from the table that cross-over percentages, compared with map distances, increase very slowly after they have once become as high as 40. According to Haldane's table, the cross-over percentage would not attain 50 until the map-distance reaches infinity.

Has the model figured in this paper any value either to confirm or to disprove the linear hypothesis? It does not, like the models of chromosomes 1 and 3, show the genes in a curved band lying in one plane. But it does show them lying roughly in a linear chain winding cork-screw fashion through the model. If all wires over 40 inches long were cut, the system would straighten out so as to approach a linear arrangement. I conclude that the model supports the linear hypothesis, if it be supposed that the longer distances have been shortened by double crossing-over, and that map distances in such cases should exceed observed cross-over percentages.

[1] These PROCEEDINGS, **5**, 25, 32, and 500.

[2] *Carnegie Inst. Washington, Publ.* **237**, 1916.

[3] *Genetics*, **3**, 1918 (107–134).

[4] Bridges, C. B., and Morgan, T. H., "The Second Chromosome Group of Mutant Characters," *Carnegie Inst. Washington, Publ.* **278**, 1919 (123–304).

[5] Gowen, J. W., "A Biometrical Study of crossing Over." *Genetics*, **4**, May, 1919 (205–250).

[6] These PROCEEDINGS, **5**, May, 1919.

[7] Haldane, J. B. S., *Genetics*, **8**, Sept., 1919 (306).

THE DEVELOPMENT OF CONNECTIVE TISSUE IN THE AMPHIBIAN EMBRYO

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Communicated by R. G. Harrison. Read before the Academy, November 10, 1919

The researches[1] in which the author has been engaged for several years have shown, in brief, that the structure of the plasma clot of frog's blood is of such a nature that when influenced by the proper mechanical factors, e.g., tension or pressure, its structure will be radically changed. In cases of this kind a fusion and consolidation of the minute elements of the clot will take place and, as a result, long fibers will be formed which unite in wavy bundles, anastomose with other bundles and ramify in various directions throughout the clot, thus resulting in the formation of a material which, at least in its morphology, is like certain types of connective tissue. In wounds in frog's skin, the experiments showed that a fibrous tissue formed from a plasma clot functioned, at least temporarily, as a normal connective tissue and there was no evidence to show that it would ever be replaced.

The above results led naturally to the question as to whether a similar process normally takes place in the histogenesis of connective tissue in amphibian embryos. The results obtained from these investigations are as follows:

1. The primitive forerunner of connective tissue in frog embryos is an amorphous, gelatinous material which, because of the fact that it stains

very lightly in the early stages by any of the numerous methods tried, is difficult to detect. This ground substance can be demonstrated around the notochord soon after it is formed and shortly before the embryo has reached the tail bud stage. A little later this material, which is to form a part at least of the connective tissues, surrounds the medullary cord and a layer of it, following the body wall, extends ventrally on either side and in time completely encircles the body cavity. The formation of this matrix around the notochord occurs before there is any syncytium of the mesenchyme cells in this region. In fact, at this stage, the cells here present have not yet assumed the shape of typical mesenchyme cells which later appear. It is evident, therefore, that this primitive ground substance of connective tissue has arisen as an intercellular secretion of the embryonic cells[2] and not by a syncytial fusion of cytoplasm.

2. The ground substance having been formed, cells begin to move into it and wander through it. These are spherical at first but, as they move through the ground substance, they soon change into various shapes, becoming stellate, spindle-shaped, etc. The study of the sections shows that, in general, individual cells do not separate from the cell masses and move out into the various cavities and open spaces of the embryo until after the formation of the secreted ground substance which is the forerunner of the connective tissues. The present work, therefore, adds additional evidence in support of the conclusions which Harrison[3] and others have reached with regard to the stereotropism of cells in tissue cultures. Cells, whether in tissue cultures or in the developing embryo, have need of a supporting framework of some kind in order for migration from the main masses to take place.

3. The connective tissue fibers begin to arise in the ground substance soon after it has formed. In some cases, they form in the ground substance in regions which are free from cells so that it is very clear that they have not arisen by any intracellular action. Instances can be noted in which it appears that the fibers are formed by a gradual transformation of the ground substance, first, into a delicate net-like structure and then into the long fibers which are typical of connective tissue. In its morphological features, at least, this process gives evidence of being identical with the one previously observed in the transformation of the plasma clot.

4. In other regions of the ground substance into which the cells have wandered, the formation of the fibers can also be shown to be due to changes in the ground substance and not to a sloughing off of the cell protoplasm. A differential stain, such as Mallory's connective tissue stain, shows very clearly the limits of the cell cytoplasm and the beginning of the ground substance. In many cases the paths of the cells can be traced through the ground substance and the possibility arises that, in their movements through the ground substance, they may give off secretions which play a part in the final chemical constitution of the fibers.

However, the fact that the fibers can form in a cell-free ground substance shows that no part of the cell cytoplasm is necessary for their differentiation from the ground substance.

5. Any satisfactory theory of connective tissue formation must take into account the well-established fact that the great mass of the connective tissues, both ground substance and fibers, is formed when not in contact with cells. The adherents of the intracellular theory of connective tissue formation, holding that both ground substance and fibers are living material, although of a different grade from that in cells, maintain that the embryonic connective tissue after it has been formed by an intracellular action has the power to grow through the assimilation of food material, and the ability to differentiate new fibers.[4]

6. The results of the present researches may be summarized as follows:

(*a*) The origin of connective tissue lies in an intercellular secretion of the embryonic cells. This secretion constitutes the ground substance of the connective tissues and it increases in amount during development not by an assimilation of food materials and consequent growth but by the continued and additional secretions given off by the embryonic cells.

(*b*) This ground substance secreted by the cells is of such a nature that, under the influence of various chemical and mechanical factors, it forms the connective tissue fibers by means of a consolidation of the minute elements of which it is composed in apparently the same way that a transformation of the plasma clot occurs.

[1] Baitsell, G. A., (*a*) *J. Exper. Med.*, **21**, 1915 (455); (*b*) *Ibid.*, **23**, 1916 (739); (*c*) *Amer. J. Physiol.*, **44**, 1917 (109).

[2] The presence of a primitive ground substance has been demonstrated by various investigators. E.g., see Merkel, F., *Anat. Hefte*, **38**, 1908 (321); and Szily, A., *Ibid.*, **37**, 1907 (649). Both of these articles contain a full review of the literature.

[3] Harrison, R. G., *J. Exper. Zoöl.*, **17**, 1914 (521).

[4] E.g., see Heidenhain, M., *Plasma und Zelle*, pp. 33, 38, etc.

CALCIUM AND MAGNESIUM METABOLISM IN CERTAIN DISEASES

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Communicated by L. B. Mendel. Read before the Academy, November 10, 1919

We wish to present some observations upon calcium and magnesium metabolism in leprosy and in multiple exostosis.

Clinically, leprosy is characterized by a *loss* from the body of bone salts; in multiple exostosis bone salts are *added* to the organism for the calcification of the new growths. It is thus apparent that in these two abnormal conditions the processes involved in calcium and magnesium

metabolism must stand in sharp contrast. The literature contains little data relative to mineral metabolism in either of these diseases.

In the present investigation the general plan followed was to place the subjects of experimentation upon a known diet low in calcium and magnesium for a definite period. Calcium or magnesium was then added for a second period. Calcium intake was increased by the administration of milk. Magnesium was given in the form of the citrate. By the procedure outlined it is apparent that the organism was given a distinct task to perform. The manner in which this task was accomplished by the diseased organism was judged by comparison with normal subjects maintained under similar experimental conditions.

The experiments were made upon six subjects divided as follows:

(*a*) 2 normal subjects. (*b*) 2 leprous subjects. (*c*) 2 exostosis subjects.

In the study of leprosy one subject represented a well-advanced case; in the other the disease was in an incipient stage.

With exostosis one subject had advanced to the stage where the abnormal processes had become stabilized; the other case represented the active, less advanced stage of the disease.

Results.—When compared to normal individuals under the same experimental conditions leprous patients retain calcium in relatively large quantities whether the individual is maintained upon a calcium-poor or a calcium-rich diet; and the greater the intake of calcium the greater is the relative retention. In the more advanced stage of the disease the degree of retention is greater than in the early phase.

This retention cannot be explained by differences in calcium intake or by variation in the power of absorption. It is apparently an evidence of a metabolic demand for calcium induced by the disease. Clinically, it may be inferred that there is a need for calcium; experimentally, the organism gives evidence of this need by retention of calcium administered.

The study of magnesium exchange in normal and leprous subjects demonstrates that in the advanced stage of leprosy there is a tendency for a retention of magnesium. The degree of retention is much less marked than in the case of calcium.

With the exception of the retention of calcium and magnesium the leprous organism responds to changes in intake of calcium and magnesium in the same manner as that exhibited by the normal subject.

It is, perhaps, self-evident that the loss of bone salts in leprosy is but a manifestation of the disease processes. Nevertheless it is quite conceivable in dietary conditions where calcium is not particularly abundant that the lack of this element may play a material rôle in the rapidity of the progress of the disease. Conversely, the suggestion is pertinent that the progress of the disease may be greatly retarded or perhaps even alleviated if an abundance of calcium is present in the diet.

The suggestion that plenty of calcium and magnesium be supplied in the food in leprosy as a therapeutic measure is at least worthy of trial.

Multiple Exostosis.—From a consideration of the study of multiple exostosis it may be concluded that in the stabilized stage of this disease calcium exchange differs little from that of a normal individual whether the abnormal subject is maintained upon a calcium-poor or a calcium-rich diet.

In the progressive stage of the disease calcium metabolism is markedly different from the normal in that calcium is lost from the body in relatively large amounts when the subject is maintained upon a calcium-poor diet. This excessive elimination of calcium is excreted by both the urine and feces in a normal ratio. When placed on a calcium-rich diet calcium is retained in the body to an extent not widely deviating from that obtaining in normal subjects. A resumption to a calcium-poor diet again induces excessive calcium elimination.

In the stabilized stage of multiple exostosis magnesium excretion is two or three times as great as the intake whether the subject is maintained upon a diet poor or rich in magnesium.

In the progressive stage of the disease the general type of magnesium excretion resembles that of the stabilized stage but the *degree* of elimination is not so marked.

Magnesium added to the diet in the stabilized stage results in the prompt excretion of the same. The same test applied to the progressive stage gives evidence of the retention of some magnesium. The degree of retention, however, is much less than that shown by normal individuals.

Absorption of both calcium and magnesium in multiple exostosis is not inferior to that of normal subjects.

The facts enumerated suggest that in the early stages of this proliferative type of bone disease under discussion a check may perhaps be given to the progress of the disease by proper dietary procedure—restriction of calcium and magnesium intake.

Summary.—Clinically, in leprosy there is evidence of loss of bone salts; experimentally, the leprous organism gives evidence of a marked tendency to retain or conserve bone salts, more especially calcium.

Clinically, in multiple exostosis it may be inferred that bone salts are added to the body; experimentally, in the progressive stage of the disease the organism attempts to rid itself of bone salts, particularly calcium. In the stabilized stage the organism throws out excessive quantities of magnesium.

These facts suggest possible beneficial results in treatment by the institution of proper dietary procedures.

THE LARGER OPPORTUNITIES FOR RESEARCH ON THE RELATIONS OF SOLAR AND TERRESTRIAL RADIATION[1]

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Communicated by the National Research Council, December 8, 1919

The earth is maintained at its present temperature by a balance between the solar radiation received and the terrestrial radiation emitted. The mean intensity of the solar radiation as it is at the earth's mean distance outside the atmosphere is believed to be well known. However, it appears to be variable from year to year and also irregular over short intervals of days, weeks or months. These variations, which have been discovered and to a certain extent followed for about fifteen years by the Smithsonian Astrophysical Observatory at its station on Mt. Wilson, have lately been compared with terrestrial temperatures and atmospheric pressures at different stations of the world by several meteorologists, notably by Clayton, and it appears that the effects of solar variations are important as governing changes of terrestrial temperature.

This indicates two highly desirable researches: First, to make daily observations of the sun competent to determine its variations. Second, to determine by further statistical inquiries the exact influence of the variations of the sun on the terrestrial phenomena.

In order to carry out the first research thus outlined, it requires not less than four special solar radiation observing stations in the four most cloudless regions of the earth. One such is now in existence at Calama, Chile, where it is being maintained by the private funds of the Smithsonian Institution. If there was available the necessary income of thirty or forty thousand dollars a year, the Institution would establish the required observing stations and would arrange for the daily wireless transmission of the results obtained on solar radiation so that they might be available for meteorologists in all parts of the world to use for forecasting purposes. The same could be done by international coöperation if due regard were given to making the measurements homogeneous. It is not probable that any steps of this kind will be taken within a year or two. By that time the series of measurements being made at Calama, Chile, will enable meteorologists to determine to what extent the results will be valuable for forecasting purposes.

It would promote the proposed solar investigation if there could be devised autographic recording instruments for determining the exact value of the cloudiness at all times of the day when the sun is above the horizon. Hitherto measurements of cloudiness have been made at comparatively few stations, and as they depend upon personal estimates of observers who are apt to overlook wisps of cirrus clouds especially dangerous for solar radiation work, and as they are usually taken only two

or three times in the day, they are quite inadequate to enable the investigator interested in establishing solar radiation stations to select the regions of the earth best meeting his requirements of cloudlessness. It would, therefore, be a very valuable investigation if some suitable autographic method of measuring cloudiness could be devised simple enough to be employed at numerous stations reported to be cloudless.

The whole subject of the cloudiness of the earth is very important. Recent measurements of Aldrich show that a cloud surface reflects about 78% of the solar radiation incident upon it. As the cloudiness of the earth is reputed to be about 50%, it is obvious what a large part clouds play in determining the temperature. They are effective not only in cutting off incoming radiation from the sun but also outgoing radiation from the earth. If the simple autographic apparatus above mentioned were available, it should be employed at numerous stations in all parts of the world and if possible on the ocean.

The measurement of solar radiation at several stations on the earth's surface by means of the pyrheliometer has occupied observers in many countries. Several series of observations have been carried on for many years by the U. S. Weather Bureau, and are published in excellent form in the *Monthly Weather Review*. Many copies of the Ångström pyrheliometer and of the Smithsonian silver disc pyrheliometer, whose constants are both so well known as to form together a homogeneous system of pyrheliometry, have been sent out to many quarters of the world. Only a few series of regular observations are at the present time being conducted with them, and it is greatly to be hoped that a large number of such series may be conducted regularly in the future. The method of reducing the results and publishing them can hardly be improved over that which is followed by the United States Weather Bureau, and that may well be taken as a model.

The study of the outgoing radiation from the earth has lately been carried on by several observers, notably by Mr. Fowle, who has investigated the effects of water vapor in long atmospheric columns in diminishing the rays of long wave-length such as the earth sends out. His investigations extend only to a wave-length of 17 microns because no suitable optical media transparent to waves of longer wave-length are available. It appears that potassium iodide may be such a medium and it is hoped shortly to produce large crystals of the salt suitable for making prisms for the study of long wave-lengths of terrestrial radiation.

In the meantime, valuable information has been obtained on terrestrial and atmospheric long wave-length radiation by Dr. A. K. Ångström by the use of the pyrgeometer or nocturnal radiation instrument devised by his father. An instrument applicable for the same purpose has also been devised by Messrs. Abbot and Aldrich of the Smithsonian Institution and is called by them the pyranometer. Neither instrument is entirely

satisfactory for very long waves since both depend upon a knowledge of the absorption of blackened surfaces to long wave-lengths, and this is a matter which still lies in doubt. For satisfactory progress in this line of the measurement of nocturnal radiation, a new instrument depending upon the principle of the hollow chamber or absolutely black body ought to be devised.

The study of the effect of ozone on the temperature of the earth is one which ought not to be neglected. Next to cloudiness and atmospheric humidity, ozone is thought to play the most important part in its effect on terrestrial radiation; first, because the quantity of ozone in the atmosphere is believed to be variable, and, second, because its effect upon terrestrial radiation occurs near the wave-length 10 microns where water vapor is almost completely transparent. This research should include the determination of the variations of the quantity of atmospheric ozone and the measurement of the effect of its changes on the ozone band near 10 microns in wave-length.

A fuller discussion of the several points which have been raised above will be found in the following papers.

INVESTIGATIONS IN SOLAR RADIATION

Survey of the Present State of the Field

We may inquire: First, what is the intensity of the radiation of the sun on which all the life of the earth depends; second, is this intensity constant or variable from day to day and from year to year, and what are the effects of variability, if any?

1. *The Solar Constant.*—The question of the absolute amount of the solar radiation interests us not only for our own sake but for the sake of the future generations. What a valuable thing it would be if we knew at this time the intensity of the sun's radiation as it was in the times of the Egyptians and the Babylonians, and as it was in the intervening periods of Rome and the Middle Ages. It is plainly our duty to transmit to posterity accurate measure of the intensity of the sun's radiation as it is now, so that they will be in a better position in this branch of science than we find ourselves. We cannot expect to know the intensity of the sun's radiation as it would be in space at the earth's mean distance (that is, the so-called "solar constant of radiation") to that high degree of accuracy which we are accustomed to demand in many branches of physics. If we determine that value to one per cent, it is all we may reasonably hope for, because the intervention of the earth's atmosphere, with its changing amounts of haze and cloudiness will always interpose to the investigator an insuperable obstacle to the highest degree of accuracy. It may be that in the future apparatus can be shot up by means of rocket devices to go outside of the atmosphere altogether, but probably the sources of error of automatic apparatus for such a research will be found so large

that no greater degree of accuracy than to one per cent will be possible even with them.

The spectrobolometric investigations of this subject by the Astrophysical Observatory of the Smithsonian Institution which have been continued for the last seventeen years have yielded the general indication that the value of the solar constant of radiation is within one per cent of 1.93 calories per square centimeter per minute. This result is confirmed by experiments made with sounding balloons by the same observatory in coöperation with the U. S. Weather Bureau in 1914. Automatic recording pyrheliometers were sent to a height of about 25 kilometers. It was found that the intensity of the radiation there, at a point where 24/25 of the atmosphere was beneath the observing instrument, fell within the range of solar constant values as obtained by spectrobolometric work at the surface of the earth. The actual value obtained by the balloon work was 1.84 calories per square centimeter per minute. Allowing for the obstruction of the sun rays by the still superincumbent atmosphere a reasonable extrapolation would give 1.88 calories. This differs from 1.93 calories less than the error of the observations and is well within the range of solar constant values obtained at different days from surface observatories.

Apparently the close agreement of these widely different independent methods of obtaining the intensity of solar radiation outside our atmosphere permits us to say authoritatively that the mean value of the solar constant is at any rate between 1.9 and 2.0 calories per square centimeter per minute and most probably not greatly different from 1.93. A few men cling to the view that much higher values should be set for it—values between 3 and 4 calories per square centimeter per minute, but their arguments carry little weight, as it seems to me, and those best qualified to know are agreed that the values given above have a strong foundation.

The methods of observing the solar constant of radiation by means of the spectrobolometer have been carefully worked out and the whole subject has been published with satisfactory fullness and is in shape to be transmitted to the scientific men of the future in order to enable them to reproduce the measurements or to compare their own measurements with the results now obtained.

2. *The Sun's Variability.*—Passing now to the second branch of the subject, the investigations of the Smithsonian Astrophysical Observatory conducted at Washington, Mt. Wilson, Mt. Whitney, Bassour (Algeria), and now the investigations supported by the Smithsonian Institution from its private funds in North Carolina and Chile have all united in giving the impression that the solar radiation is not constant, but varies from day to day through a range of certainly five and possibly at times ten per cent. The conclusion that the sun is a variable star is confirmed in several ways but most notably by the results of measurements made by

the Smithsonian Astrophysical Observatory at Mt. Wilson, California, on the distribution of energy along the diameter of the solar image. These measurements indicate, as was well known before, that the edge of the sun's disc is less bright than the center, and that the contrast of brightness between the center and the edge varies according to the wave-length of light, being greater for short wave-lengths, less for long.

But the measurements of recent years have shown that not only is there a variation of contrast by wave-length, but also a variation of contrast with the time. The contrast in each wave-length is different for different days of observation and, on the average, for different years of observation. The changes of contrast have been compared with the changes of total radiation of the sun determined by the aid of the pyrheliometer and spectrobolometer, and it is found that there is a moderate degree of correlation between them. The correlation is of two kinds. For variations of long periods of years, high values of the solar constant are found associated with high values of contrast between the center and edge of the sun. On the contrary, for the short period variations of the solar radiation, occupying a few days, weeks, or months, it is found that high values of the solar radiation are associated with diminished values of the solar contrast.

The cause of this two-fold variation is reasonably explained. When the sun grows hotter and thus increases its output of radiation along with increased solar activity, as indicated by sun spots, prominences, and other visible solar phenomena, this would tend to cause a greater degree of contrast. For since if the solar temperature were zero there would be zero contrast, the higher the temperature the higher the contrast. But the sun is probably entirely gaseous, and certainly its outer layers are so, and these may become more turbid at times, just as the earth's atmosphere becomes more hazy at some times than at others. Accompanying increased turbidity of the solar atmosphere there would be found a diminished value of the solar constant of radiation. But since the path of the solar ray is oblique in the solar atmosphere near the edge of the sun, the path is longer there and the effects of the turbidity would be greater at the edges rather than at the center. Thus with the increase of turbidity the contrast of brightness would increase accompanying a diminished value of the solar constant of radiation. In this way it appears that the two-fold variations of the sun which have been found may be reasonably explained.

Investigations Required

1. *Solar Radiation Stations.*—We now pass to the applications of this discovery of the variation of the sun. What effects does it have upon the climate of the earth and upon other terrestrial phenomena? In order to cover satisfactorily this interesting and utilitarian branch of the investigation it is necessary to have good solar observations daily. Unfortunately there is no region in the world where the sky is so free from cloudiness

that a single observatory can obtain daily measurements of the intensity of solar radiation as it is outside the earth's atmosphere. The spectrobolometric investigation of the solar constant of radiation requires that the observations shall extend over several hours from the time when the sun's altitude is small to the time when it is large, so as to determine for many wave-lengths of the spectrum what increase of intensity corresponds to the diminution of the length of the path of the solar rays within the earth's atmosphere. In order to prevent error in the determination of the transparency of the earth's atmosphere, the sky must be uniformly clear during the interval just mentioned.

This is a condition very hard to fulfil. All stations in the world fulfil it well enough for certain days of the year, some stations for very many days of the year, but none for all. The experience of the Smithsonian Astrophysical Observatory in these matters indicates that probably there is no region in the world where more than 250 satisfactory days in the year can be confidently expected. Accordingly, it is highly desirable if these solar radiation changes have notable effects upon the earth's temperature and other meteorological and terrestrial phenomena, that several observatories shall join in making the measurements of the solar constant of radiation from day to day. On every day at least two values should be obtained strictly comparable with one another in their method of observation and with a probable accuracy as far as experimental work is concerned to the order of one per cent. The mean of two, or still better, of three or four such values, would give a probable accuracy of the final result to better than one per cent, and if a series of such observations extending over every day in the year for a course of several years were available, it would probably be possible to determine very well the effect of the changes of solar radiation on the terrestrial climate.

In order to carry on the work in this way, a considerable income is required. The experience of the Smithsonian Institution in its several expeditions to Africa and to South America, and to the western part of North America, indicates that an income of between five and ten thousand dollars, preferably as much as eight thousand dollars per year, for each station would be requisite. If four stations should be considered competent to carry out the problem, it would, therefore, require a yearly income of from thirty to forty thousand dollars for the whole series. It would be preferable that the work should be under a central direction so that the various measurements might be strictly comparable and homogeneous. If the Smithsonian Institution, with its long experience in these matters, had available for this purpose an income of the amount specified, that would offer a good way of dealing with the problem.

On the other hand, it may be that support for the project would be more easily obtained if the several governments of the regions where the observatories for this purpose might be favorably located should be ap-

proached and asked to take over the work. The establishment of such new observatories seems not to be urgent for another year, until the results obtained in Chile by the Smithsonian Expedition shall have been compared with the climate of Argentina, as is now being done by Mr. Helm Clayton, so as to see if there is a well-justified expectation that solar observations of this kind will be useful in meteorology.

2. *Autographic Cloud Observers.*—Looking to the possible establishment of such solar constant observing stations, the most important preliminary investigation relates to the choice of the most favorable situations. Experience hitherto has shown that the reported results of observations of cloudiness by meteorological services do not give a sound index of the availability of situations for this exacting work. In all of our experiments we have invariably been disappointed in not observing as many days as the reports of the cloud observations have led us to expect. Certain portions of the earth, it is true, have the reputation of being cloudless, among them the Chilean Desert, the Central and Western Provinces of Australia, some parts of South Africa, Upper Egypt, the Desert of Sahara, the Desert of Arabia, regions in British India, and possibly others. What would facilitate the establishment of solar observing stations more than anything else, in case they should seem desirable, would be to have a long series of cloud observations obtained by strictly automatic processes, independent of the judgment of observers, for a considerable number of the most promising regions, such as those I have mentioned. Such observations should cover the whole period when the sun is above the horizon.

Dr. Humphreys has proposed to me an instrument for such a preliminary investigation of cloudiness. It is based on the principle of photographing a reflecting ball from above. The sensitive surface would be that of a moving film or plate which would be exposed for an instant once in a quarter or half an hour, as would be most convenient, and would, therefore, give a series of photographs of all the clouds which occurred in the sky at the instants of observation. If this or some other suitable automatic device for photographing the whole sky could be prepared and employed by the meteorological services of the world which operate in the most cloudless regions, the work of establishing solar constant stations, if these should be needed, would be materially advanced. Otherwise, there is no method except to go to a region that is recommended and be disappointed and sorry that the region was chosen but without knowing where else to go, just as has occurred before. This is a disheartening, costly and time-consuming process, and might, perhaps, be avoided in the way above suggested.

3. *Pyrheliometric Observations.*—While the measurement of the solar radiation by means of spectrobolometric work is the only thorough way available in which to determine the variation of the sun, situated as the observer must necessarily be beneath an atmospheric sea full of haze and

other obstructing materials, yet it is highly important to have measurements of the radiation of the sun made at the earth's surface in many parts of the world. A series of measurements of this kind is being conducted by the U. S. Weather Bureau at its stations in Washington, Madison, Lincoln, and Santa Fe. This work, in charge of Professor Kimball, has gone on now for about ten years, and is being published in excellent form in the *Monthly Weather Review* of the U. S. Weather Bureau. Observations were also undertaken in Egypt and a report was published several years ago by Dr. Shaw. Observations were carried on for a number of years by the Harvard College Observatory at Arequipa, in Peru, but about a year ago the instrument was accidentally broken. The Arequipa series was then discontinued, partly because the Smithsonian Institution has its spectrobolometric and pyrheliometric station in Chile not far from Arequipa. Some measurements are being made also in Argentina, Brazil and elsewhere. There are also pyrheliometric instruments at the Island of Teneriffe which were in use before the war, but whether the measurements are being conducted there regularly now I am not aware. Dr. Dorno, of Davos, Switzerland, has made such measurements with many others of related subjects for a long time, and has just published a great volume of valuable results.

It would be very desirable if work of this kind could be carried on regularly at favorable stations employing strictly comparable instruments. There are about thirty copies of the Smithsonian silver disc pyrheliometer distributed to a number of different parts of the world but as stated above it is not probable that during the period of war they have been in regular use. Many of them are in very cloudy localities.

4. *Distribution of Radiation over the Solar Disc.*—As stated above, it has been found at the Smithsonian observing station on Mt. Wilson, in California, that the distribution of radiation along the diameter of the solar disc is subject to variability of two kinds—one of a long period of years, and the other of a short period of days, weeks, or months, and that these two kinds of variation are fairly closely correlated with the variations of the total radiation of the sun. The work of observing the radiation along the solar diameter requires the use of a long focus telescope and a spectrobolometer, and may very readily be carried on nearly simultaneously with measurements of the solar constant of radiation. Such investigation is going on regularly at Mt. Wilson during the summer season when the Smithsonian observers are working there. Perhaps it would not be necessary to set up other stations since the main object of this work was accomplished when it was shown that it confirmed the existence of the solar variability shown by the measurements of the solar radiation itself.

The method of observing the distribution of brightness along the solar diameter which we have adopted is to stop the clock-work of the coelostat

which reflects the solar beam into the long focus telescope, so that the solar image drifts across the slit of the spectrobolometer in an east and west fashion. The question was, therefore, open for some time whether the distribution at right angles to this, that is, along the north and south diameter of the sun, would be substantially the same. In 1918, Mr. Aldrich investigated this matter by the aid of special mechanism associated with the coelostat and was able to show that if any difference in distribution exists between the north and south and the east and west diameter of the solar image, respectively, it is too small to recognize by this method and, indeed, is less than one per cent.

INVESTIGATIONS OF THE RELATIONS OF TERRESTRIAL CLIMATE TO RADIATION

Survey of the Present State of the Field

1. *Kinds of Radiation Concerned.*—The temperature of the world is maintained by the balance between the income of solar radiation and the outgo to space of terrestrial radiation. The former is principally included between the wave-lengths 0.3 and 3.0 microns. The latter is principally included between the wave-lengths 5.0 and 50 microns. Substances which are transparent for the one may be opaque for the other, though in these long ranges of wave-lengths substances may pass through several minima or maxima of opacity and transmissibility. Apart from cloudiness, which is the principal factor, the radiation of the sun is principally hindered in its passage to the surface of the earth by the water vapor of the terrestrial atmosphere and by the scattering of the molecules of the air and by the dust which the air carries. The losses of the direct solar beam by scattering from air molecules and dust are largely compensated for by the indirect solar radiation received from the whole hemisphere of the sky. On the other hand the rays lost from the direct beam by absorption in the water vapor of the earth's atmosphere, while they go to warm the atmosphere itself, are very differently applied to maintain the heat of the earth as a planet than they would be if they reached the earth's surface.

2. *Absorbents of Terrestrial Radiation.*—Apart from cloudiness, which is the principal hindering factor, the outgoing radiation of the earth's surface to space is hindered mainly by water vapor, ozone, and carbon dioxide. Of these the principal obstruction is water vapor which absorbs powerfully over great ranges of spectrum. The other two absorbents are each confined in their absorbing regions to comparatively narrow ranges of spectrum, but the ozone absorption band, at about 10 microns, occurs in a region where water vapor absorbs scarcely anything while the carbon dioxide absorption band at about 14 microns occurs in a region where water vapor is also powerfully absorbing. The atmospheric proportion of carbon dioxide is sensibly constant, while water vapor and ozone are variable. Accordingly, while water vapor is certainly the most important of the three,

probably ozone, although much less plentiful in the atmosphere, and certainly not more powerful as an absorber for the spectrum of a perfect radiator than carbon dioxide, is yet entitled to be regarded as second in importance on account of this peculiar posture of affairs.

3. *Studies of Terrestrial Radiation and Its Atmospheric Absorption.*—The study of these absorbing elements and their influence upon the spectrum has been carried on to a considerable extent by several investigators, notably by Paschen, Rubens and his collaborators, Miss Eva von Bahr, and lately by Mr. Fowle of the Astrophysical Observatory of the Smithsonian Institution. Mr. Fowle's researches[2] comprised the examination of the spectrum of the Nernst Glower up to a wave-length of about 17 microns, particularly as it is affected by the absorption occurring in long columns of atmospheric air containing known amounts of humidity and carbon dioxide. The experiments deal with quantities of from 0.003 to 3.0 centimeters of liquid water disposed in the atmosphere as water vapor. Owing to the lack of a suitable transparent refracting medium for optical purposes beyond the wave-length 17 microns, the important region of the terrestrial spectrum extending from 17 to 50 microns could not be investigated by Mr. Fowle. Somewhat later, Mr. Aldrich of the Astrophysical Observatory of the Smithsonian Institution made a long series of experiments (as yet unpublished) with crystals both natural and artificial and with other available substances, endeavoring to discover one which would be suitable for making a prism transparent to these rays. The only substance found which seemed to be notably superior to rock salt is potassium iodide, and this material has hitherto been available only in very minute crystals. Promising experiments made at the General Electric Company indicate that large crystals of potassium iodide for prisms may soon be available. If so, it will be possible to carry on this valuable spectrum investigation over a region hitherto very little explored. The dependence of terrestrial radiation on water vapor has been investigated to a considerable extent in another way by Dr. A. K. Ångström, who made observations in Algeria, Southern California, and lately in Sweden with the pyrgeometer, a nocturnal radiation measuring instrument invented by K. Ångström. Dr. Ångström's measurements were conducted during several months at a considerable number of stations varying in altitude from near sea level to that of Mt. Whitney, 4,400 meters, and in dryness from desert conditions to those of considerable humidity. At the same time measurements were made of the humidity prevailing in the air, partly at the surface by means of psychrometers and partly in the free air by means of kites and sounding balloons under the management of the United States Weather Bureau. This valuable investigation was supported by the Hodgkins Fund of the Smithsonian Institution, and was published as Vol. 65, No. 3, of the Smithsonian Miscellaneous Collections.

Investigations Required

1. *Ozone and Radiation.*—Very little is known concerning the influence of ozone on the earth's radiation. It is certain that a conspicuous band of this substance occurs at the wave-length of about 10 microns, where water vapor is almost completely transparent. It is a little hard to see how the investigation of the influence of ozone can be best undertaken. The region of 10 microns is very difficult to work with in the solar spectrum. All terrestrial surroundings give out waves of this wave-length. It is as if the investigator of the visible spectrum were troubled with stray light from every direction upon his photographic plates or other means of observation. Furthermore, and still more serious, the more intense rays of the solar spectrum, coming from regions of much shorter wave-length, are continually encountered as stray light in the spectrum, even hundreds of fold greater in intensity than the rays of the spectrum at the region in question. Rock salt must be employed for the optical train and its hygroscopic character is a serious difficulty. Finally the measurements ought to be quantitative in terms of energy. Something can be done to avoid stray light by reflecting the solar beam by means of several silvered ground glass mirrors. In this way the shorter wave-lengths are scattered, while the longer wave-lengths desired are reflected by virtue of the greatness of their wave-length, compared with the roughness of the mirrors. Yet the prospects of getting good bolographic representations of this region of spectrum day after day are not good. Perhaps the quantity of ozone existing in the air could be determined daily by measurements made in the ultra-violet spectrum by the aid of photography and these results could be compared with measurements of the nocturnal radiation made after the method of Ångström. Allowance being made for variations of temperature and water vapor, the influence of variations of the ozone might then appear. At all events, determination of the effects of ozone on the terrestrial radiation is a desirable investigation though so extremely difficult.

2. *Cloud Observations.*—The effect of clouds on terrestrial temperature is extremely important. Recent measurements by Mr. Aldrich of the Smithsonian Institution, made from a military balloon, show that a smooth layer of clouds reflects about 78% of the total direct and indirect solar radiation incident upon it from the sun and sky. Investigations of the quantity and distribution of the cloudiness of the surface of the earth have been published by Tisserenc du Bort, and Arrhenius. They depend, however, on very imperfect material. Cloud observations are much more fragmentary than temperature observations, and besides are not based upon standardized instruments in general, even if there be such, but are based on observers' estimates of the proportion of the sky obscured. The matter is so fundamental to the proper understanding

of the temperature of the world and its dependence on the balance of radiations of the sun and earth that it warrants careful attention. Some simple autographic means, theoretically satisfactory and instrumentally accurate, ought to be provided for estimating cloudiness, and this should be installed with the least possible delay at all first-rate meteorological stations in the world, and indeed as extensively as possible. The instrument should not be merely applicable to land conditions, but ought to be available for ships. It is hardly possible to overestimate the importance of this neglected branch of meteorology.

3. *Standard Instruments for Nocturnal Radiation.*—As mentioned above, Dr. Ångström has employed the pyrgeometer for an extensive and valuable research on nocturnal radiation and the determination of atmospheric re-radiation at different temperatures and under various other meteorological conditions. There has also been devised at the Smithsonian Institution, by Messrs. Abbot and Aldrich, an instrument called the pyranometer, which is applicable for the same purpose. Neither of these instruments, however, is thoroughly satisfactory, for this reason: They both present blackened flat surfaces which radiate towards the atmosphere and space, and it is assumed in the theory of the instrument that the absorbing and radiating properties of the blackening upon these strips is known. Experiments, however, seem to show that the materials used for the blackening purposes become less and less satisfactory for the longer wave-lengths, so that for rays beyond 15 microns there is a strong chance that the instruments are very imperfect. In order to really cover the objection it is necessary to produce a nocturnal radiation instrument which employs the well-known hollow receiver principle of the "black body." This is a matter of some difficulty because the intensity of the radiation to be considered is small, and it must be emitted and received at all angles within a hemisphere. There are very formidable difficulties in the way of a satisfactory solution of this requirement, but in order to give really definite information as to the nocturnal radiation of the earth and atmosphere they must be overcome. Associated with this problem is a definitive solution of the question of the constant of the fourth power radiation formula of Stefan. The measurements hitherto made by physicists on this constant, usually called σ, are in considerable disaccord. The margin of possible error is, perhaps, not very large, but it cannot be allowed as certain that we know this constant within 2%.

4. *Statistical Studies.*—As already stated, the sun is known to be a variable star. The effect of its variations on the terrestrial climate has lately been investigated to a considerable extent by Mr. H. H. Clayton[2] of Buenos Aires. Investigations of a similar kind have been made also by Dr. Arctowski of New York and by Dr. Helland-Hansen and Dr. Nansen[3] of Norway. These investigators have all reached the conclusion that the variations of the sun reported by the Smithsonian observers

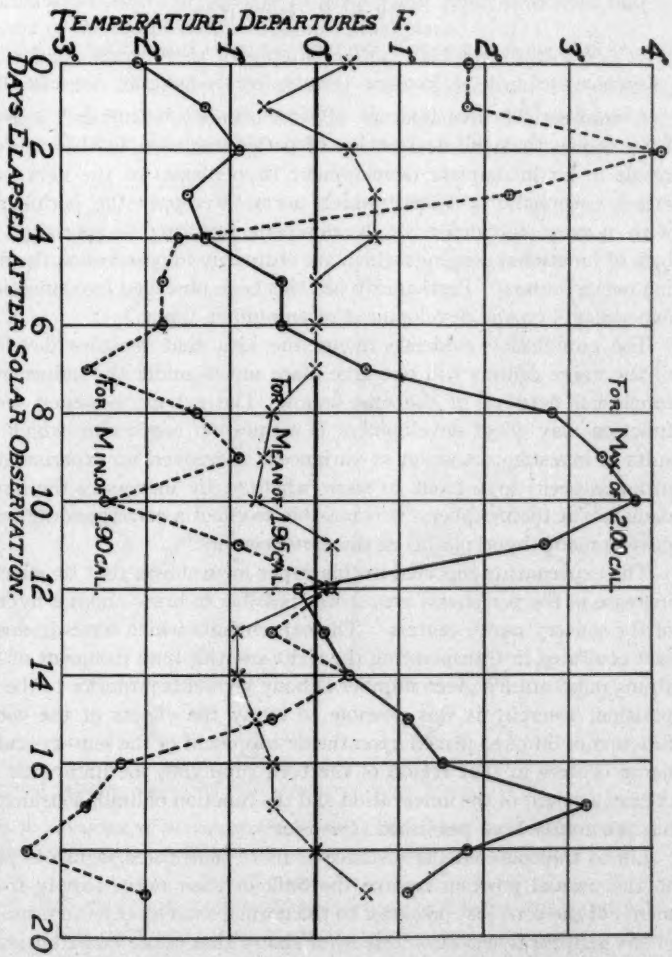
at Mt. Wilson affect terrestrial temperatures to a considerable extent and also induce variations of terrestrial atmospheric pressure. Mr. Clayton's investigations have led him to the conclusion that the tropical and the polar regions of the earth are made warmer by temporary increases of solar radiation, while the temperate regions both north and south of the equator are made cooler by the same increase of radiation. Dr. Nansen, however, is of the opinion that when more thorough studies of the matter have been made, it will be found that the effects are not thus zonal, but rather are associated with the great action centers of atmospheric circulation. Dr. Nansen's view is that since a considerable portion of the sun's radiation is absorbed by the clouds, dust and water vapor in the atmosphere, a change in the amount of solar radiation may produce notable changes in the atmospheric circulation, and these, by altering the direction of the prevailing winds, may alter indirectly the temperature of meteorological stations. Hitherto the amount of investigation of the variation of the sun has been inadequate to give very satisfactory data to work with in determining these correlations. The present expedition of the Smithsonian Institution to Chile, it is hoped, will be continued for several years and will enable meteorologists to trace this relation much more thoroughly. Mr. Clayton, from the studies he has made and is making, is very sanguine about the value of solar radiation observations such as are being made by the Smithsonian observers.

The accompanying illustration, prepared from Clayton's studies, shows the remarkable courses of temperature departures at Buenos Aires, following high, intermediate and low values of the solar constant of radiation.

A very great deal of additional statistical inquiry is already possible in view of the series of solar constant observations reported by the Smithsonian observers on Mt. Wilson. There is now a much more continuous series of results available extending from July 27, 1918, as obtained at Calama, Chile. Meteorologists should be in a position to study these observations in connection with the temperature, pressure, cloudiness and wind at a very great number of stations distributed as well as possible over the earth's surface. It is only by such laborious investigation that a sound basis can be laid for the improvements in forecasting which Mr. Clayton thinks are now possible.

If it shall appear from such statistical investigations that the variations of the sun are really important for forecasting purposes, and if it shall prove possible to establish three or four additional solar radiation stations, widely scattered in the most cloudless regions in the world, then we may contemplate the possibility that from each such solar radiation station the results of each day might be sent out by wireless telegraphy, to be employed by the meteorological stations of the different countries for forecasting purposes. Experience in Calama, Chile, indicates that with a staff of three industrious and energetic persons it is possible to

compute and send out the result of morning observations of a given day before night-fall. A brief empirical method for the determination of solar


TEMPERATURE DEPARTURES F.
-3° -2° -1° 0° 1° 2° 3° 4°
DAYS ELAPSED AFTER SOLAR OBSERVATION.
0 2 4 6 8 10 12 14 16 18 20
FOR MIN OF 1.90 CAL.
FOR MEAN OF 1.95 CAL.
FOR MAX OF 2.00 CAL.

THE GREAT AND PROLONGED INFLUENCE OF SOLAR CHANGES ON TERRESTRIAL TEMPERATURE

Average march of the mean temperature of Buenos Aires for 19 days following high, mean and low values of the solar constant of radiation for the years 1913, 1914, 1915 and 1918, in the months May to November. Solar radiation determined at Mount Wilson, California; temperatures by Argentine Weather Service.

radiation has lately been devised at Calama and seems satisfactory, so that it is possible that the result of a morning of observation may be telegraphed to the world by noon.

[1] This is issued as the second of a series of research surveys prepared under the auspices of the National Research Council. Reprinted in *Reprint and Circular Series of the National Research Council*, Number 7.

[2] *Smithsonian Misc. Coll. Washington*, **68**, No. 3, 1917.

[3] Now in course of publication by the Smithsonian Institution.

ON THE HYPERPLASIA OF NERVE CENTERS RESULTING FROM EXCESSIVE PERIPHERAL LOADING

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A number of investigators (Braus,[1] Shorey,[2] Dürken,[3] and Burr[4]) have shown that the destruction of peripheral areas in the embryo may result in an incomplete development (hypoplasia) of the nerve centers, either encephalic or spinal, which normally supply the peripheral area with nerves—the defective development resulting, supposedly, from a lack of functional demands which are ordinarily imposed upon the developing nerve centers. Particularly has this been observed in connection with experiments on the development of amphibian limbs.

The cumulative evidence favors the idea that *complete* development of the nerve centers will not take place unless under the influence of the functional activity of the end organ. The extent, however, to which function may effect development is a question concerning which the results of investigators stand at variance. Moreover, no experiments have hitherto been carried out to show whether, by increasing the functional demands at the periphery, it is possible to effect a corresponding increased development (hyperplasia) of the nerve centers.

The experiments reported in this paper have shown that by effecting an increase in the peripheral area it was possible to bring about a hyperplasia of the sensory nerve centers. The experiments which have disclosed this fact consisted in transplanting the right anterior limb rudiment of Amblystoma punctatum a given number of body segments posterior to the normal position, whereby it was possible to study the effects of the continued function of limbs so placed upon the development of the sensory and motor nerve centers in that region of the cord supplying the limb with nerves. A brief account of the innervation and the function of limbs so transplanted has previously been published (Detwiler[5]).

Limbs transplanted the distance of more than three segments posterior to the normal position receive the bulk of their nerve supply from segments of the cord just posterior to the normal limb level. An examination of the peripheral nerves of this level shows that those contributing fibers to the functioning transplanted limbs are larger than their counterparts which are not connected with a limb.

In an endeavor to show whether this increase in the number of peripheral neurones was due to a hyperplasia of the motor centers, attempts were made to compare the number of motor nerve cell bodies in both halves of the spinal cord at the level in question. The larvae having been preserved at a relatively young stage (sixty to seventy days after the closure of the medullary folds), it was impossible to differentiate accurately be-

tween the nervous and non-nervous cells. Nevertheless, the results obtained from counting approximately eighty thousand cells, in addition to a comparative study of the size of the ventral roots, indicated that a hyperplasia of the motor centers had not taken place.

The evidence, however, of a hyperplasia of the sensory centers was very specific. In case $AS4_{26}$ the right anterior limb, which was transplanted the distance of four segments posterior to the normal limb level, was innervated by the fifth, sixth and seventh segments of the cord—the normal

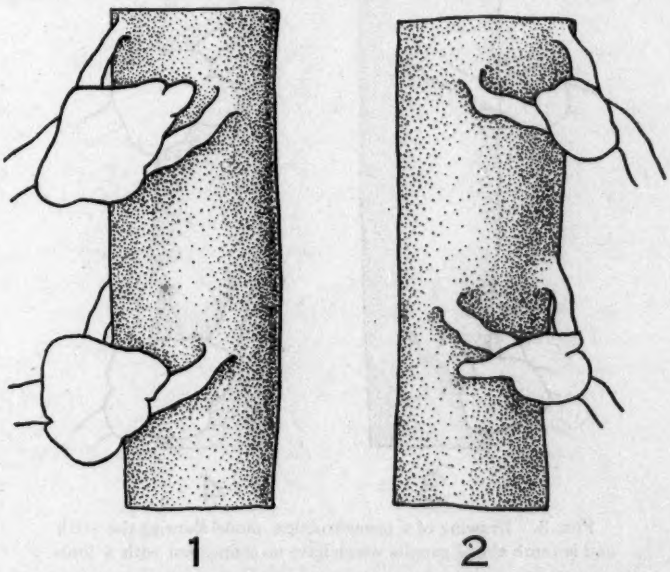

FIG. 1. Drawing of a reconstruction model showing the third and fourth left spinal ganglia (connected with the normal intact limb). × 50

FIG. 2. Drawing of a reconstruction model of the third and fourth spinal ganglia showing great reduction in size as a result of excision of the limb. × 50

intact left limb receiving its innervation from the third, fourth and fifth segments.[6] The right sixth and seventh spinal ganglia (connected with the transplanted limb) were found to be considerably larger than the corresponding ganglia on the left side (not connected with a limb), the comparative sizes being illustrated in figures 3 and 4. The results of counting the sensory nerve cells in the ganglia on the two sides showed clearly that the hypertrophy was due to a marked hyperplasia of the cells. The removal of the limb from its normal position, likewise, resulted in a marked reduction in the sizes of the third and fourth ganglia which normally supply it with sensory nerves (figs. 1 and 2).

By counting the cell bodies in the third and fourth ganglia on the left (those connected with the normal intact limb) and comparing with the number counted in the corresponding ganglia on the right side, where the peripheral area was greatly diminished as a result of the limb excision, a cell ratio between the normal and hypoplastic development was obtained. Further, by counting the number of cells in the sixth and seventh ganglia on the left (normal) side and comparing with the number found in the

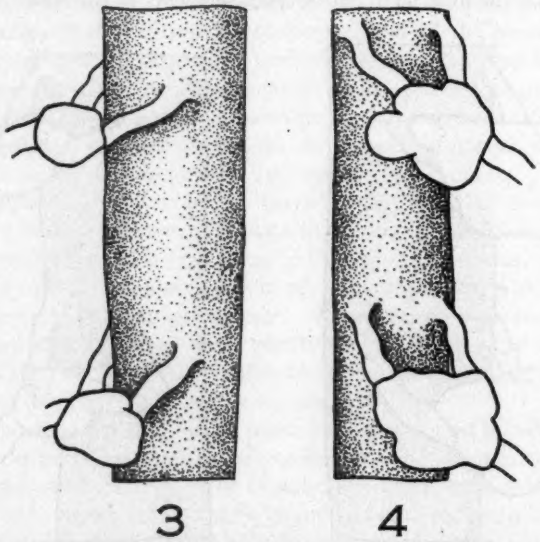

FIG. 3. Drawing of a reconstruction model showing the sixth and seventh spinal ganglia which have no connection with a limb

FIG 4. Drawing of a reconstruction model showing hypertrophied sixth and seventh spinal ganglia supplying afferent innervation to a transplanted limb

right sixth and seventh ganglia, which contributed innervation to the transplanted limb, it was likewise possible to obtain a ratio between the normal and the hyperplastic development. A cell count was also made of the right and left ninth ganglia, which supplied homologous and undisturbed peripheral areas, as a control for the hypoplastic and hyperplastic cell estimates.

Having determined the cell ratios, the weight ratios were obtained by weighing and comparing the weights of unassembled paper models of the ganglia. The results of both computations (cell and weight) are summarized in the accompanying table. The extensive hypoplastic development of the right third and fourth ganglia resulting from the limb excision is readily seen, the total number of cells in each ganglion being less than

half the number present in the corresponding left ganglia with the limb intact. This is also emphasized by comparing the weights of the ganglia, the weight of the right third and fourth being less than half that of the corresponding left ganglia. The cell and weight ratios as seen in the table show an interesting approximation. The hyperplastic development of the right sixth and seventh ganglia connected with the transplanted limb is seen by comparing the number of cells in these structures with the number present in the corresponding left ganglia. A ratio closely approximating that of the cell count is shown by comparison of the weights.

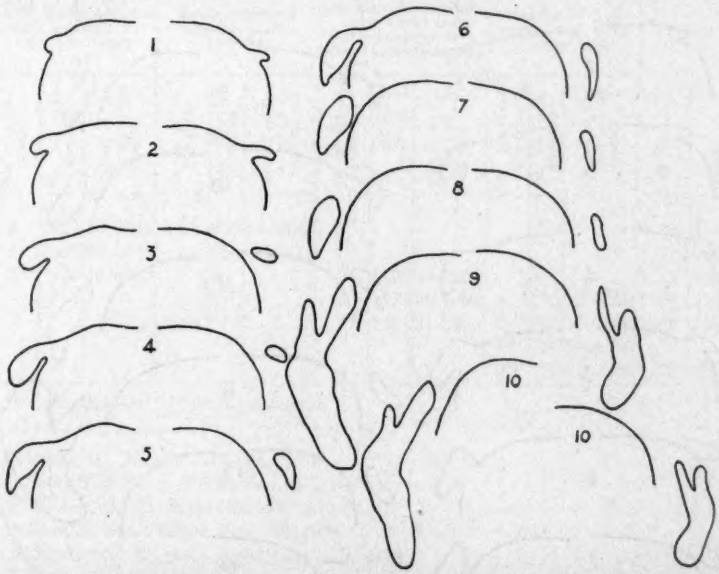

FIG. 5. Camera lucida drawing, showing serial sections of the sensory roots of the right and left third spinal nerve. The right root is greatly reduced in size as a result of excision of the right limb with which it is normally connected. × 40

Although a cell count of the fifth ganglia is included in the table, the results have no comparative value since both supply nerves to a limb. The cell content of the right ganglion connected with the transplanted limb is seen to be slightly greater than that of the left ganglion connected with the normal intact limb. The cell and weight ratios of the ninth ganglion which were used for a control show only an inappreciable difference which is well within the limit of error.

The number of cells in a given ganglion was estimated by counting the nuclei. The diameter of the nuclei in many cases being greater than the thickness of the section (10 μ), a considerable number of cells must have been counted twice. The percentage error being the same, however, in

all ganglia, regardless of size, a constant factor is introduced which has no appreciable effect on the cell ratios.

Hyperplasia of the sensory centers was also demonstrated by an increase in the size of the posterior (sensory) roots. The latter which were connected with the transplanted limb on the right side were found to be considerably larger than those on the left side, not connected with a limb

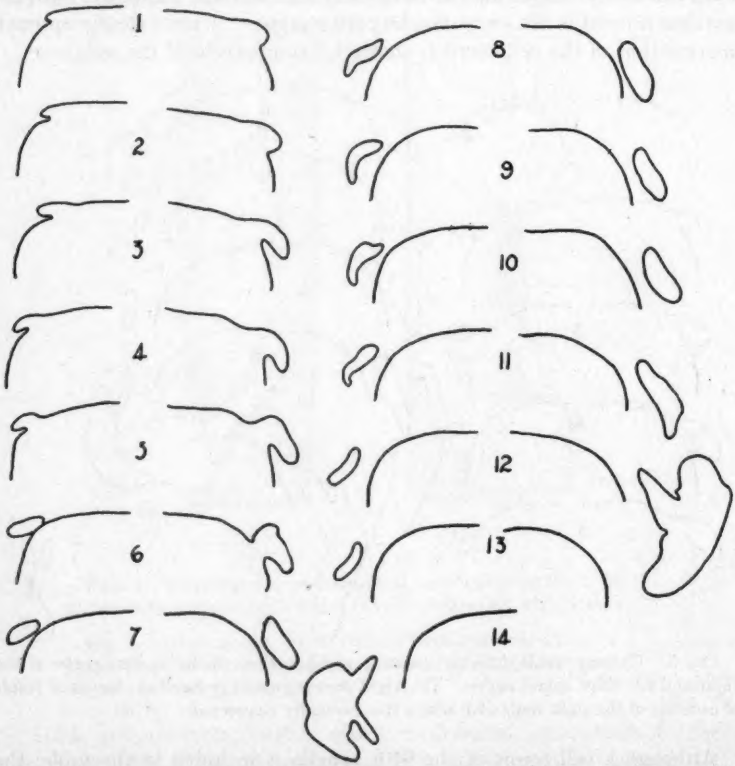

FIG. 6. Camera lucida drawing, showing serial sections of the sensory roots of the right and left seventh spinal nerve. The right root being connected with the transplanted limb is considerably larger than the left, which has no connection with a limb. × 40

(fig. 6). The hypoplasia of the sensory centers resulting from extirpating the limb was likewise shown by a great reduction in the size of the sensory roots, normally connected with the limb (fig. 5).

The results reported in this paper, as well as confirmatory evidence obtained from the study of other cases not reported ($AS5_{25}$, $AS5_{26}$, $AS5_{27}$, $AS5_{30}$), clearly show that excessive peripheral loading with a subsequent increase in the functional demands will result in a corresponding hyper-

plasia of the sensory nerve centers. Results so far accumulated suggest the possibility that motor regulation is accomplished by division of the peripheral axones. It is hoped that further experimentation will disclose a number of additional facts concerning the effect of peripheral overloading on the development of nerve centers.

SHOWING THE EFFECTS OF REMOVAL OF THE LIMB AND THE FUNCTUAL ACTIVITY OF THE TRANSPLANTED LIMB UPON THE DEVELOPMENT OF PERIPHERAL AFFERENT NEURONES

GANGLION CONNECTED WITH NORMAL INTACT LEFT LIMB			GANGLION WITH RIGHT LIMB REMOVED			GANGLION CONNECTED WITH RIGHT LIMB TRANSPLANTED TO A HETEROTOPIC POSITION			GANGLION NOT CONNECTED WITH EITHER LIMB			RATIOS	
No. of spinal ganglion	No. of cells counted	Weight of the model in grams	No. of spinal ganglion	No. of cells counted	Weight of the model in grams	No. of spinal ganglion	No. of cells counted	Weight of the model in grams	No. of spinal ganglion	No. of cells counted	Weight of the model in grams	Cell No.	Weight
3	1725	30.4841	3	850	12.9748							0.492	0.425
4	1430	26.1604	4	685	9.7311							0.479	0.372
5	955	16.8798				5	1195	22.2939				1.25	1.32
						6	1171	26.5422	6	693	12.6600	1.69	2.09
						7	1084	21.7634	7	720	11.7366	1.51	1.85
									9*	754	15.5456		
									9**	773	17.2328	1.02	1.10

* Left ganglion. ** Right ganglion.

[1] Braus, H., *Morph. Jahr.*, **35**, 1906.
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